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Development of Construction and Use Criteria for Sanitary Landfills

Los Angeles Department of County Engineer

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DEVELOPMENT OF CONSTRUCTION AND USE CRITERIA FOR SANITARY LANDFILLS

Final Report on a Solid Waste Management Demonstration Grant

This final report (SW-19d) on work performed under solid waste management demonstration grant no. G06-EC-00046 to the County of Los Angeles, California, was prepared by the DEPARTMENT OF COUNTY ENGINEER, County of Los Angeles, *and* ENGINEERING-SCIENCE, INC.

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The report details the results of a three-year project intended to formulate construction criteria for sanitary landfills and improvements that would lead to optimum land development and maximum use. The investigation of landfills that had been built in an uncontrolled fashion led to the conclusion that the movement of gas away from landfills can be minimized and that ultimate subsidence can be predicted. In addition, a leachate pollution index was established, a model ordinance for locating, constructing, and operating sanitary landfills was drawn up, and research suggestions were developed.

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NOTE TO THE READER

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The results of this project are not considered to be generally applicable in all locations outside the Los Angeles area. The project was conducted by the County of Los Angeles, and most of the field investigations were made at landfills in the County. As a general rule, sanitary landfills in the study area are large; many are very deep. The criteria developed herein reflect the requirements of this type of disposal operation and are, therefore, not necessarily applicable to smaller and/or shallower landfills common in other parts of the country.

Before utilizing information developed by this project the reader is cautioned to consider how specific conditions in his area may relate to, or differ from, those of the study area. Such factors as climate, topography, geology, and hydrology, as well as the characteristics and quantities of wastes received, should be evaluated, because each may influence the design of a sanitary landfill operation.

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CHAPTER I

INTRODUCTION

PROGRAM OBJECTIVES

The County of Los Angeles, State of California, in order to formulate construction criteria for sanitary landfills and improvements which would lead to optimum land development and maximum use, conducted a three-year program of investigation and demonstration into the problems associated with land disposal of refuse. This program was developed in cooperation with the Environmental Protection Agency, Office of Solid Waste Management Programs, formerly the Bureau of Solid Waste Management, United States Public Health Service, Department of Health, Education and Welfare, and was funded in part through Solid Wastes Disposal Study and Investigation Grant No. G06-EC-00046. Engineering-Science, Inc. was retained by the County of Los Angeles on 7 March 1967 to serve as the principal consultant to Los Angeles County for the study.

BACKGROUND

Landfilling of municipal refuse is expected to continue for many years to be the most economical and principal means of ultimate disposal in many areas of the United States. Present alternative methods such as incineration offer interesting challenges but are either too impractical or too costly. There are problems associated with disposal on the land; however, open dumps and burning must be prohibited throughout the nation in the interest of health and safety.

Over the years, communities have developed, surrounded, and encroached upon many completed disposal sites, often resulting in unattractive, potentially hazardous conditions within highly populated areas. Proper sanitary landfilling procedures and controls can result in the creation of land surfaces suitable for useful purposes. Also, certain existing less desirable topographical features, such as useless pits, ravines, and canyons may be eliminated by strategic landfill location and landscaping. During the program Los Angeles County, Department of County Engineer, and Engineering-Science, Inc. were engaged in the study of the subjects of gas movement, groundwater pollution, fire hazard, construction of landfills, maintenance of completed sanitary landfills, and construction on and adjacent to completed sanitary landfills.

The problem of landfill control within highly populated areas has two facets: (1) that concerned with existing and completed landfills which were built in an uncontrolled fashion without close regard for gas and leachate movement; and (2) that concerned with prospective landfills for which control devices and procedures can become part of the process of operating and constructing the sanitary landfill. In existing and completed landfills, gas and leachate migrations may be difficult to control. For new landfills, however, it will be possible to provide built-in gas and leachate control. Gas control devices or systems include properly placed well points, wells, gas ventilation mechanisms, burn-off devices, and monitoring apparatus.

The major factors affecting the integrity of improvements on top of, within, and adjacent to sanitary landfills are gas movement and settlement of the fill. These factors are interrelated because both are influenced by the amount of the decomposition in the refuse.

Significant results of the study include: (1) favorable conclusions regarding methods for minimizing gas movement away from landfills; (2) establishment of a leachate pollution index; (3) a method of predicting ultimate landfill subsidence under controlled conditions; (4) criteria for a model ordinance and uniform standards for locating, planning, designing, operating, and constructing sanitary landfills and subsequent improvements on or adjacent to landfills; and (5) suggestions for future research.

MANAGEMENT OF THE STUDY

Mr. John A. Lambie, County Engineer, served as Project Director. The study was under the direct supervision of Mr. Carroll D. Smith, former Division Engineer, Industrial Wastes Division; and Mr. J. K. Bryant, Division Engineer, Project Planning and Pollution Control Division. Assisting Mr. Smith and Mr. Bryant were Mr. Charles G. Brisley, Jr., Assistant Division Engineer, Project Planning and Pollution Control Division; Mr. Kenneth Harvey, Civil Engineer; and other County staff members. Engineering-Science, Inc. personnel who participated in the project under the direction of Mr. Robert L. White were Mr. Myron Ellis Nosanov, Mr. Ralf C. Carter, Dr. William E. Gates, Dr. Houshang Esmaili, Dr. Timothy G. Shea, and Mr. G. Scott Robertson.

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Mr. Wallace Koster, Engineer and Geologist, National Disposal Contractors Company, Barrington, Illinois
Mr. Robert N. Farvolden, Professor of Geology, University of Western Ontario, Ontario, Canada
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SITE SELECTION

During the first year of the study, 1967, local sanitary landfills were inventoried, examined, and evaluated. Activities included the measurement of the extent of migration of refuse produced gases in sanitary landfills, investigation of the geometry of existing sanitary landfills, preliminary identification of the properties of the soil affecting gas movements, the introduction of gas control devices into the existing landfills, and the establishment of gas and subsidence monitoring controls at strategic locations on existing landfills. Sites selected for study during the first year were located within Los Angeles County, Orange County, and the San Francisco Bay Area. Within Los Angeles County, 76 landfill sites were considered and screened for compliance with criteria formulated for the selection of the study sites. These criteria were as follows: (1) the fill should have been completed or be available without modifications over the planned three-year study period; (2) original ground topography should be known; (3) the type, quantity, and method of refuse placement should be known; (4) the thickness and type of final cover materials should be known; (5) historic data relative to past settlement or gas movement would be valuable, but not essential; (6) local geology should be known or subject to reasonable assessments; and (7) where private property is involved, cooperation of the landowner must be reasonably assured. Eight sites were selected for study under the first-year work program, and were assigned numbers (Figure 1-1). Settlement surveys performed by another public agency were reported for a ninth site. Twenty-seven waste disposal sites in the San Francisco Bay area were reviewed for suitability for studying gas production and settlement in landfills subject to tidal action. Legal problems of jurisdiction and the continued operation of the sites for the disposal of excavated material from the Bay Area Rapid Transit Project limited the final selection to one site. This site is in an area reclaimed from San Francisco Bay and is surrounded by dikes keeping sea water from overflowing the fill. A site in Orange County was also studied.

GAS BARRIERS AND CONTROL DEVICES

A major objective of this study was to design and implement various types of gas barriers and control devices to effectively retard subsurface gas migration. Trenches, wells, and exhaust systems were considered. The excavation of a cutoff trench backfilled with highly permeable gravel and rock proved to be an effective method for the control of gas movement. Two other gas control systems were developed. One of these systems consisted of five wells located about 100 feet from the completed landfill. Each well was excavated to the equivalent depth of the refuse and operates on the basis of combined gas suction and air flushing. The objective of this control system is to reduce the flow of gases beyond the plane passing through the axes of the wells. Suction is developed by an electrically powered blower. Another control system consisted of an asphalt type membrane installed under a greenhouse constructed directly upon a fill. This barrier is designed to prevent gases from moving through the fill cover into the confinement of the greenhouse. Perforated pipes were placed in gravel vents at each end of the membrane to prevent gas pressure under the membrane. In all cases probes were installed and the results of the sampling programs indicated all systems were effective.

A total of 388 gas probes at depths varying from two to eight feet were used to sample, analyze, and provide data for use in plotting contours of equal methane or carbon dioxide concentrations around each landfill. Correlations were developed between the pattern and extent of methane movements, the nature of soil, including permeability and limited data on the formations, and the effect of existing gas control devices.

Natural soils were tested for suitability as gas barrier membranes in a series of laboratory experiments. Four soils with different particle size distributions were independently tested in a laboratory diffusion column at two levels of moisture content and three conditions of gas inflow pressure. Diffusion-dispersion coefficients for each soil were determined by an analytical solution of the differential equation governing the flow of gases through porous media. This resulted in a basis for calculating the flow rate of gases through these soils under different conditions of soil moisture, compaction, and gas pressure, thus establishing the relative degree of effectiveness of the soils tested as gas barrier membranes.

Gas production studies during the project indicated and verified the need for tracing the movement of gases from many existing sanitary landfill sites. The results indicated that potentially hazardous situations may be identified, observed, and controlled.

FIELD SUBSIDENCE MONITORING AND LABORATORY EXPERIMENT PROGRAM

Measuring the subsidence of monuments and survey points, established at six selected sites during the first year of the project study, was continued throughout the study period to determine optimum frequencies and minimum-maximum time requirements for field subsidence monitoring. Cumulative settlement-time relationships were developed for the monuments being monitored to correlate with cumulative settlement expressed as a percentage of depth versus time.

In order to interpret known field conditions at one site, equal-depth-of-fill lines were compared with equal-cumulative-settlement lines.

Parameters of subsidence were analyzed during a laboratory experiment for investigating subsidence characteristics of decomposing refuse materials. The parameters investigated included the nature of the refuse, initial and subsequent compaction, and volume reduction caused by biological decomposition, saturation, and leaching. The experiment introduced these and other variables under aerobic and anaerobic conditions. The materials (paper, garbage, garden waste and wood, metal, glass, ceramics, rags, plastics, and inert soil) were synthesized into typical refuse samples and compacted in the programmed sequence. Weights, temperatures, and subsidence of decomposing materials were monitored and compaction tests were made when decomposition of the organic materials became negligible. The results of this program were input to the task of predicting ultimate landfill subsidence.

PREDICTIONS OF ULTIMATE SUBSIDENCE

Ultimate subsidence in sanitary landfills is analogous to that in soils with respect to the consolidation ratio and the coefficient of compressibility. Consolidation ratio is frequently called consolidation and is expressed in a percent and is referred to as the percent consolidation. The coefficient of compressibility is the stress-strain ratio of the soil, numerically equal to the slope of the curve on the natural scale plot of pressure versus void ratio. The theoretical study of consolidation utilizes an equation from which the pressure and void ratio values may be known at any point and at any time in a stratum of consolidating soil of any thickness. The change in overall thickness of the strata after any interval of time may be determined from the equation. This is known as the Terzaghi consolidation theory. A major portion of the theory is the idealized pressure versus void ratio and homogeneous materials leading to a limitation upon the application of the theory. To apply the assumption of homogeneity, any analyses of ultimate subsidence must be accompanied by maximum control over the materials within the landfill. An additional limitation is that the Terzaghi theory assumes complete saturation of the materials.

The hypothesis upon which the theory is founded is important to any engineer using the theory to predict settlements. The coefficient of consolidation determined by laboratory data involves a varying number of variates at each moment of time. The method of fitting a curve to plotted laboratory data is critical to precise determinations but not necessarily to practical determinations.

It should also be noted that plastic time lag and plastic structural resistance to compression are phenomena not considered in the Terzaghi theory. These, too, are variables and are complicated by ecological processes such as decomposition, gas production, leachate production, and accompanying production of internal voids.

Direct use of the maximum ultimate subsidence anticipated in a sanitary landfill based upon the theory developed under laboratory test conditions is a meaningful first step in the direction of developing necessary technology. The next step is to determine a means of predicting the time required for ultimate subsidence. Subsequently, it may be possible to predict intermediate time-subsidence relationships.

EFFECTS OF SANITARY LANDFILLS ON GROUNDWATER QUALITY

Groundwater quality degradation as a result of sanitary landfilling may occur through: (1) percolating water carrying away liquids of undesirable quality; (2) percolating water dissolving undesirable waste fractions; and (3) gases generated within the fill diffusing downward and outward to be dissolved in the groundwater. A detailed study of leachate production characteristics, as a function of the stage of decomposition of typical refuse materials, was conducted in the laboratory. During the experiment the rate of leachate production and the total quantity of leachate expected for a given volume of refuse were examined. Samples were systematically leached in the laboratory, and leachates were analyzed for total dissolved solids, chemical oxygen demand, hardness, alkalinity, pH, organic and ammonia nitrogen, chlorides, sulfates, and nitrates. Total dissolved solids was used as an index for determining the quantity of solutes leachable from refuse fills. Filtration, ion exchange, and adsorption are among the major processes affecting the composition of leachates which percolate through soil formations causing change in the leachate concentrations.

AVAILABLE INFORMATION ON USES AND PROBLEMS ASSOCIATED WITH SANITARY LANDFILLS

Available information on landfills throughout the United States was obtained by mailed questionnaires, visits to completed sanitary landfills, and interviews with selected experts. The completed sanitary landfills visited were those upon which improvements had been constructed. A total of 272 short-form questionnaires and 41 long-form questionnaires were returned. Nineteen completed and reused sanitary landfill sites were visited and seven experts were formally interviewed, four of whom have been quoted with their permission. Numerous ordinances controlling sanitary landfills throughout the nation were reviewed. The scope of control was evaluated and formatted for input into "Model Ordinance Criteria." During the three years of the project all obtainable literature was reviewed and examined for project applicability.

The use, as developable real estate, of completed sanitary landfills was widely reported. Reports on the suitability of sanitary landfills for development included favorable comments and opinions but emphasized the need for detailed attention to design for controlling the problems. Factors affecting problems reportedly associated with sanitary landfills are: (1) percentage of organic debris; (2) moisture content; (3) daily soil cover; (4) weather conditions; (5) final soil cover; and (6) age of fill (Tables I-1, I-2, and I-3).

Land uses on completed landfills include athletic fields, botanical gardens, golf courses, parks, parking lots, playgrounds, salvage and storage areas, mobile home parks, residential, and commercial and industrial uses. Many of the completed landfills have provided beneficial uses for the completed landfill property. Severe damage to some surface structures and subsurface improvements was observed.

Most building codes do not recognize the need to protect structures located adjacent to refuse fills from the possible hazards of landfill produced gases; however, gas control measures should be incorporated before or during construction of the landfill. Also, buildings, surface improvements, and subsurface structures will be damaged if constructed on sanitary landfills without proper regard for potential differential settlement.

Materials and methods for safe construction of surface structures on or near sanitary landfills were evaluated. Observations made during site investigations and information obtained from the data survey, indicated that a variety of structural materials and construction techniques have been utilized in structures built on sanitary landfills. The surface requirements of a sanitary landfill were correlated with the structural requirements of improvements. The effects upon stability were considered and design alternatives were evaluated. In addition, materials and methods were analyzed for safe construction of underground installations in sanitary landfills.

Subsurface improvements were broadly categorized and actual and potential causes of damage were examined. The most commonly reported locations of breaks in utility lines were at building walls or footings and at joints or fittings. Buildings founded on piles may not settle as much as utilities which enter the building. In other cases the building or structure may settle more than the utility. Thus, differential settlement has contributed to ruptures of utility lines and has been the cause of additional settlement problems as a result of the admission of unexpected liquid into the landfill.

Recommendations were developed for design and construction techniques to minimize the effects of differential settlement and to maximize the stability of buildings, curbs, walkways, drainage ditches, culverts, driveways, streets, and underground installations on and in sanitary landfills.

DEVELOPMENT OF "STANDARD SPECIFICATIONS FOR GOOD PRACTICE"

Information assimilated during the project was collated for use in developing criteria for materials and methods for safe construction of surface structures, surface improvements, and subsurface improvements on, in, or adjacent to sanitary landfills. Previous recommendations were reevaluated on the basis of latest information and analyzed for means of implementation. "Standard Specifications for Good Practice" were developed from a compilation of the organized criteria into four separate documents (Appendix G). The "Standard Specifications" provide for administration and regulation of planning, design, construction, and maintenance of sanitary landfills; and improvements on, in, and adjacent to sanitary landfills.

The criteria may be summarized briefly as:

(1) Landfill locations should be a function of community need, general planning, and water pollution prevention.

(2) Landfill planning should include use of the completed surface in a manner compatible with the community general plan.

(3) Landfill design should implement planning and gas control on and adjacent to the site, and subsidence and settlement control on the site.

(4) Landfill materials should be controlled to a maximum practical limit, maximizing available reprocessing procedures.

(5) Landfill operation should be neat and sanitary.

(6) Landfill maintenance should be assured by funding or legal recourse.

(7) The design of an improvement on or in a sanitary landfill should be preceded by acquisition of the as-built plans, or a log of construction of the sanitary landfill and logs of borings.

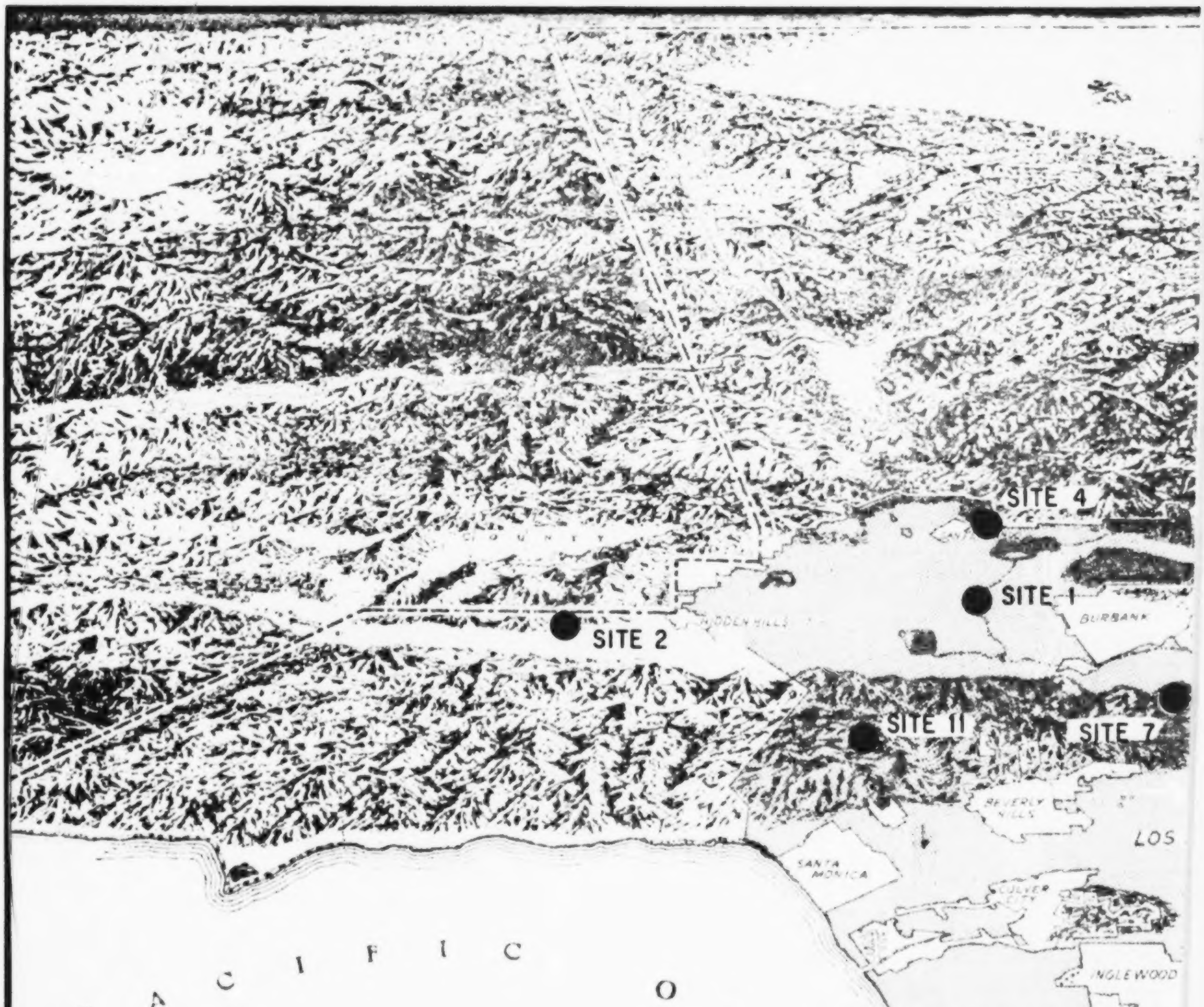
(8) Plans for improvements should be prepared by, or under the supervision of, a registered professional engineer, a licensed architect, a soil foundation engineer, or a geologist, acting within the scope of their responsibilities.

(9) Differential settlement and horizontal displacement effects must be anticipated. The choices of methods, materials, and applications should conservatively exercise cognizance of and correlate with the service and structural requirements.

(10) Detailed precautions are necessary to prevent the intrusion of gases into confined or occupied areas of buildings. Utility installations may create pathways for gases to follow. These pathways should be sealed-off or vented at manholes, vaults, basements, and other floor areas.

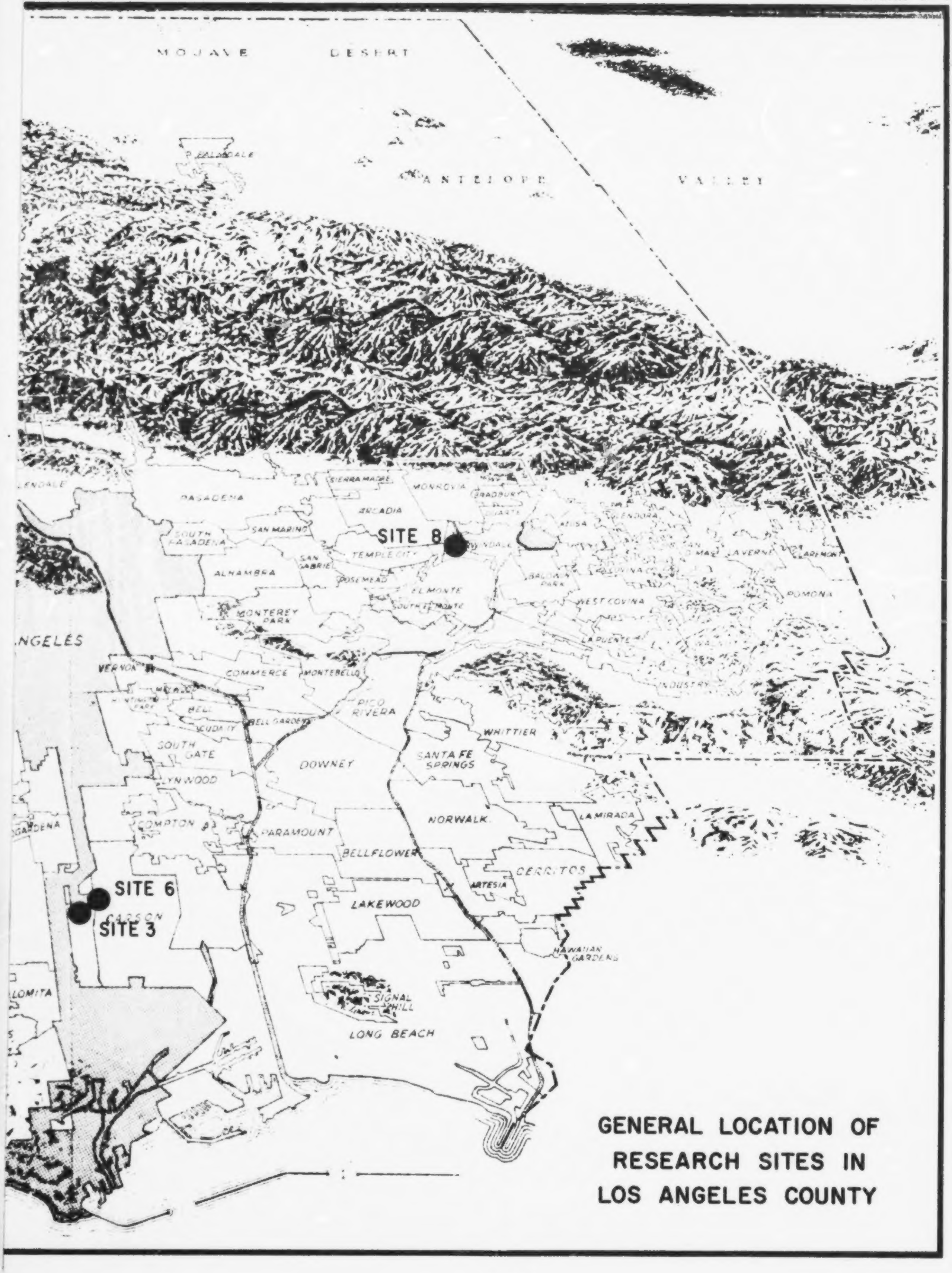
(11) The finished product of construction should not be used until certified for use under conditions which guarantee funding for possible repairs and maintenance for a specified project life.

FIGURE I-1


SITE 4
SITE 1
BURBANK
SITE 2
HIDDEN HILLS
COUNTY
SITE 11
SITE 7
BEVERLY HILLS
LOS
SANTA MONICA
CULVER CITY
INGLEWOOD
PACIFIC OCEAN
EL SEGUNDO
HAWTHORNE
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
TORRANCE
ESTATES
SITE
PALOS VERDES
ROLLING HILLS
ROLLING HILLS

GENERAL LOCATION OF RESEARCH SITES IN LOS ANGELES COUNTY

FIGURE I-1 (Cont'd)


MOJAVE DESERT
PALMDALE
ANTELOPE VALLEY
PASADENA
SIERRA MADRE
MONROVIA
BRADBURY
ARCADIA
SOUTH PASADENA
SAN MARINO
SITE 8
TEMPLE CITY
SAN GABRIEL
ROSEMEAD
ALHAMBRA
EL MONTE
SOUTH EL MONTE
AZUSA
GLENDORA
BALDWIN PARK
WEST COVINA
LA VERNE
CLAREMONT
POMONA
LA PUENTE
INDUSTRY
MONTEREY PARK
ANGELES
VERNON
COMMERCE
MONTEBELLO
PICO RIVERA
HUNTINGTON PARK
BELL
CUDAHY
BELL GARDENS
SOUTH GATE
WHITTIER
DOWNEY
SANTA FE SPRINGS
LYNWOOD
GARDENA
COMPTON
PARAMOUNT
NORWALK
LA MIRADA
BELLFLOWER
CERRITOS
ARTESIA
SITE 6
CARSON
SITE 3
LAKEWOOD
HAWAIIAN GARDENS
LOMITA
SIGNAL HILL
LONG BEACH

GENERAL LOCATION OF RESEARCH SITES IN LOS ANGELES COUNTY

CHAPTER II

MONITORING LANDFILL SUBSIDENCE AND LABORATORY DEVELOPMENT OF SUBSIDENCE PREDICTIONS

MONITORING LANDFILL SUBSIDENCE

During the first year of the study, certain completed landfill sites, or completed portions of active sites, were selected for monitoring surface subsidence, differential settlement, and lateral surface displacement. Control survey lines and monuments were established at four sites for continuous accumulation of settlement data throughout the course of the study. Additionally, settlement data on three landfill sites maintained by other agencies were periodically collected. A summary of all settlement data recorded during the project study period is presented herewith. Site descriptions are given in Reference 2.

Site 2B

Monuments and control points were established on a completed portion of active landfill Site 2. Two profile lines, approximately at right angles to each other, were staked. One line, 730 feet in length, was set with nine monuments; the other, 350 feet in length, was set with five monuments. Each monument, a standard Los Angeles County Engineer concrete bench mark, was set so that both vertical and lateral movement could be measured. Table II-1 presents settlement and lateral movement data measured during the study. Available depth data are also included.

Site 3

Site 3, completed in 1962, is a shallow fill constructed in a low slough area. Development on the site consisted of a planted and irrigated athletic field, four service buildings, and a large asphalt-surfaced parking area. Two survey lines were staked with control monuments at each end of the line and one-inch diameter iron pipes at approximately 100-foot intervals to monitor settlement. No pipes were set in the grass playing field. The surface of the turf was contour plotted for comparisons of settlement. In addition, several elevation points were established on the concrete floor slabs of the buildings. No lateral movement determinations were made at this site.

During the study, several survey points were disturbed or lost, necessitating the setting of new points or the use of surface improvements as elevation points for monitoring. Elevation and settlement data measured during the study are presented in Table II-2.

Site 4

Site 4, completed in 1961, is in a canyon from 100 to 200 feet deep. A mobile home park and a mobile home manufacturing company adjoin the site. The site over the years has experienced extensive settlement, particularly in the areas where sewage leaching fields were constructed for the mobile home park and the manufacturing company. During the study four survey lines were staked to monitor settlement, but construction work, regrading, and repaving at the site made it impractical to maintain monumentation and/or a continuous record of settlement data. Annual surveys were made, and each year new points were set; however, the data obtained from the surveys are of questionable value. Therefore, a summary of the settlement data at this site is not presented.

Site 5

Site 5, began in 1957 and completed in 1966, is from 25 to 130 feet deep and is being utilized as a botanic garden. During the study three survey lines were established. Several monuments were set on each line for monitoring both lateral movement and vertical settlement. Temporary monuments were set on the profile lines at approximately 100-foot intervals or at points of abrupt surface change for settlement measurements only. The public agency that constructed the landfill set monuments shortly after the fill was completed. These were monitored during the study.

Two comfort stations were constructed on the site during the study. Reference points were established on the floor slabs of these buildings so that any settlement data could be included as part of the subsidence monitoring program for the site.

Elevations, available depth data, and settlement data for these profile lines, monuments, and building reference points are presented in Table II-3.

Site 7

Site 7 is an active landfill under construction by a public agency. The continuing use and reuse of completed areas for stockpiling cover material prevented the establishment of a satisfactory grid system of monuments, hence no specific settlement monitoring program was established for the site. The public agency, however, did establish random monuments upon completed portions of the fill which are checked at least annually for elevation change and lateral movement. A summary of the cumulative settlement and lateral displacement, and available depth data, for these monuments since establishment through June 1969 is presented in Table II-4.

Site 9

Site 9 is a filled gravel pit constructed by a public agency and completed in 1966. The average depth is reported to be 80 feet. A grid system of profile lines, spaced 100 feet in each direction, was established on the completed surface for maintaining a continuous record of settlement. The elevation at each grid point for each year of record and the cumulative settlement of each point for the total period are presented in Table II-5.

Site 10

Landfill Site 10, located in the San Francisco Bay area, is operated by a private entity and was constructed by erecting levees around low-lying bay land. The landfill, which has been operating continuously since 1945, averages 25 to 30 feet in depth in the area that was monitored. Only one survey could be made during the study period for the determination of the rate of settlement. One section of the fill was selected, in study year 1967, for which elevation readings had been obtained in 1957 and where no additional filling had been carried out since that time. Twelve survey points were reestablished and the elevations obtained on this section of the fill. Cumulative settlement of these points for the ten-year period (1957-1967) is presented in Table II-6. In general, the survey points located at the edge of the fill next to the levee have settled less than the other points which are located on the landfill.

Site 11

Site 11 is still being filled, but certain portions of the fill have been completed. Two of these completed areas were monumented and surveyed to record settlement prior to this study. The first survey was made in 1957.

Series 100 monuments were set in December 1964 and have been periodically surveyed for elevation changes since that time. Table II-7 presents the original elevations of the points, the elevations recorded during 1969, and the total settlement of the monument points since establishment.

Series 300 monuments were set in July of 1965 and were subsequently monitored. The original elevations of these points, the 1969 elevations, and the total settlement of the monuments since establishment are also presented in Table II-7.

SETTLEMENT ANALYSES

Settlement records at Site 5 for selected monuments were plotted with cumulative settlement in feet as the ordinate and time in years as the abscissa (Figure II-1). The plots of settlement at Monument 116 and at Monument 120 indicate that the rate of subsidence is decreasing. The depths of the landfills at those points are 130 feet and 85 feet respectively. Subsidence at other monuments continues and the subsidence rate during the latter period of measurement appears to be uniform. Subsidence as a percentage of depth is shown in Table II-8.

At most of the stations plotted the settlement rate was highest during the first one and one-half years. After a one-year delay the settlement increased at an approximately constant rate. During the period of five and one-half years that measurements were made, it appears that at Monument 107 approximately 40 percent of the subsidence took place in 30 percent of the time; and at Monument 120 approximately 45 percent of the subsidence took place in about 30 percent of the time. At these two monuments a trend appears to be developing. If this trend is exhibited in the future at other locations within the landfill, an extrapolation of the curves plotted on an appropriate log base could yield a prediction of the time at which subsidence may be expected to be significantly small and not a deterrent to use of the site.

At Site 11 subsidence data was plotted for nine monuments with cumulative settlement in feet as the ordinate and time in years as the abscissa. The rate of settlement at the monuments appears constant. The curves show no significant breaks in slope that would indicate what percentage of total settlement may have taken place or allow any prediction of the duration of the settlement period (Figure II-2). However, the information indicated on Figure II-2 raises some interesting questions if used with the isopachous and settlement contours shown on Figures II-3 and II-4. On Figure II-2, three groups appear to be discernible, each showing approximately the same amount of cumulative settlement. The cumulative settlement does not seem to bear a direct ratio to the thickness of the fill. This may be observed by comparing Figures II-3 and II-4. However, in comparing these two figures, it may be observed that the greater amount of settlement appears to occur in the topographically lower portion of the fill area and this may be a function of the movement, and possible retention, of fluid in that direction. In another area at Site 11 the surface drainage appears to be from north to south, roughly across the center of the fill. The greatest thickness of fill and also the greatest amount of cumulative settlement are along a north/south line through the center of the fill with the greatest amount of settlement at the southerly end (Tables II-9 and II-10 and Figures II-5 and II-6). This appears to credit the theory that fill thickness is a factor in subsidence but is not the completely governing factor (Table II-11).

With the limitation of available field data, it is not practical to attempt to formulate predictions of the rate or ultimate amount of subsidence in a sanitary landfill. However, the field study program has developed the following conclusions, some of which may help to correlate, at some future time, with predictions developed in the laboratory:
(1) even though a cursory study of the refuse brought to a fill may yield useful data, segregation of the various materials prior to placement is generally not accomplished. Consequently, the lack of homogeneity in a fill may preclude the determination of a predictable settlement rate until characteristics of individual locations are observed over a long period of

time; (2) The principal obstacle in formulating a prediction of settlement on the basis of field observations is the lack of historical field observations; (3) Fills which may be ultimately used for purposes to which settlement is detrimental should have a greater homogeneity and maximum possible initial compaction; and (4) Data obtained from a few small demonstration fills over a period of several years is an inadequate sampling of inadequate duration. Additional observations are needed at more landfills over a much longer period of time.

LABORATORY STUDIES ON PREDICTION OF LANDFILL SUBSIDENCE

This study has been directed to laboratory evaluation of the subsidence and compaction characteristics of synthetic refuse landfills under laboratory conditions. The objective of the study was to investigate the subsidence characteristics of decomposing refuse materials of varying composition under different conditions of moisture content and surcharging and varying levels of aerobiosis.

The rate, extent, and magnitude of landfill subsidence and the load-bearing characteristics of fill areas are factors of first concern affecting future landfill use. To date, the technology available for predicting subsidence and compaction of landfills is comprised almost totally of conventional and largely empirical procedures. In many instances, because of a lack of adequate technology, the preplanning and engineering of landfill development has been nonexistent, with the attendant result that in many cases it is not even possible to describe the types and amounts of materials comprising a fill.

The increasing demand for reclamation of landfill sites has accelerated the need for the development of a rational framework of technology for prediction of the subsidence and load-bearing characteristics of the heterogeneous soil systems found in landfills. Prerequisite to the development of rational predictor equations is an evaluation of the fundamental mechanisms active in landfill subsidence. Landfill subsidence can be related to the following generic factors: initial compaction; compaction of refuse material due to surcharge loads by overlying materials; and degree of biodegradation of the organic components in the fill. A considerable body of technology exists to explain the mechanisms and cause-effect relationship active with each of these factors in the homogeneous, but not the heterogeneous environment; however, little effort has been made to examine the utility of this knowledge for predicting landfill behavior.

As an initial level of inquiry, this study is directed toward the development of relationships for prediction of the overall behavior of landfills experiencing consolidation. The primary premise of the study is that the mechanisms explaining the action of consolidating soils and of organic matter undergoing biological decomposition provide a basis for developing relationships to describe the behavior of landfills under controlled conditions and for deriving rational relationships describing these phenomena.

Controlling Factors in Subsidence and Compaction of Landfills

The overall settlement of a landfill can be caused by several mechanisms acting independently or simultaneously to alter the integrity of the landfill soil column, viz:

(1) Biological decomposition of organic matter in the fill, related to the nature and type of fill material, water content, size of material, etc., and resulting in the conversion of solid material to liquid or gaseous matter; and

(2) Compaction, during placement and due to surcharge loads exerted by overlying materials, taking place by compression of solids, compression of water and air in the voids, and by the escape of water and air from the voids.

Each of these factors must be related to corresponding functional effects on the supportive structure in a landfill before behavioral prediction is possible. Fundamental to an understanding of either of these factors is a knowledge of landfill composition.

Composition of Landfills

The general components of landfills and their significance on the settlement processes in landfills are as follows (Reference 1):

(1) Garbage: organic, putrescible, with formation of organic acids upon biodegradation; usually very wet; will partially compact but will continue to subside as decomposition progresses over long time periods;

(2) Fibrous organics, e.g., wood, paper, and fibrous wastes, will compact and decay very slowly over long time periods;

(3) Metal, e.g., cans and scrap metals, will rust and settle but can be compacted;

(4) Old tires will not decay readily and unless they are segregated or cut and shredded can cause problems if received in large numbers;

(5) Large organic materials, such as tree trunks, are slow to decay and prevent compaction of surrounding material;

(6) Large metal objects, such as auto bodies and refrigerators, are loose, somewhat compressible, and will rust but are difficult to compact and will inhibit compaction of adjacent materials;

(7) Demolition wastes, such as concrete, brick, and stone, when placed in large pieces may prevent compaction of adjacent materials and may create large voids; and

(8) Ash is fluffy and will settle, may become cemented, and can initiate corrosion of other materials.

Solid waste materials can be more broadly classified as rubbish, food wastes, and noncombustibles. Rubbish is comprised of cellulosic, plastic, rubber, oil and paint, linoleum, street sweepings, etc. Food wastes are comprised of garbage (vegetable food wastes, citrus rinds and seeds, etc.) and fats. Noncombustibles is a general classification for metals, glass and ceramics, ashes, and similar materials. The relative significance of each generic component in solid waste is related to the domestic, commercial, and industrial activities in the source area. A typical municipal refuse may contain 45 percent paper, 15 percent leaves, 10 percent garbage, five percent plastics, rags, oil, and paint, and 10 percent moisture (percent dry weight). Particle sizes of refuse components may vary from less than one inch to ten feet or more in a given load, and the characteristics of refuse collected may vary widely from load to load and day to day in a given area.

Biodegradation Processes

Biodegradation can be defined as the general process whereby organic matter is metabolized by biological agents with the production of energy for growth of the organism or organisms involved and the generation of by-product materials. The rate of progression of the biodegradation process is a function of the type of organism present, the type of substrate available for conversion, the quantity of essential nutrient materials available to the organism, and the rate at which substrate and essential nutrient materials are transported to, and by-product materials are removed from, the vicinity of the microorganisms. This succession of biodegradation can take place within two subtypes of energy-yielding metabolism, aerobiosis, or anaerobiosis, each type of which is characterized by type and rate of by-product and energy formation. The succession of substrates available can vary from all forms of soluble and insoluble matter. Microorganisms, without exception, will proliferate on the type and form of substrate most readily available for metabolism to exhaustion of that substrate before proceeding to the next most readily available form of organic matter.

The components of sanitary landfills provide a diverse pool of substrates and essential nutrients supporting a ubiquity of aerobic or anaerobic activity. The degree of aerobiosis or anaerobiosis which can take place is a function of the availability of oxygen in either gaseous or dissolved form; in the heterogeneous environment of a fill both aerobic and anaerobic microenvironments can be sustained. Water, a vital element in supporting biodegradation in a fill, serves as a vehicle for transport of essential nutrients, seed microorganisms, by-products, and gases into and through the fill. Water also provides a continuous medium for the succession of biodegradation reactions by which insoluble organic material is converted to soluble organic matter and microorganism cells, and subsequently to gases and other products. Temperature is a second vital element and the rate at which microorganisms metabolize increases rapidly with rising temperature up to limiting values lethal to the organisms.

The above observations have several relationships to subsidence as a result of biodegradation. Biodegradation processes directly attack many of the components in a landfill which provide structural strength to the fill mass. Organic acids are typical metabolic by-products which destroy materials providing integrity to the fill structure. The generation of voids, as biodegradation progresses, promotes consolidation under the weight of the fill and creates the opportunity for sporadic movement of finer materials into the open voids.

A final factor of biodegradation related to subsidence is the rate at which decomposition of the biologically available materials progresses. Microbial growth is inherently an autocatalytic process in which the amount of living substance increases in geometric progression with time, as long as substrate and essential nutrients are available. Thus (in an aggregate sense, and in a soil solution at a reasonably constant temperature) the rate of decomposition of readily available organic matter would be expected to increase exponentially to a point at which continued decomposition is limited by substrate exhaustion. If it is assumed that the rate of subsidence caused by decomposition processes is proportional to the rate of decomposition, then subsidence would be expected to progress at an exponentially increasing rate to the point of substrate depletion. It is expected that the actual rate of subsidence due to decomposition will be attenuated or amplified by such environmental factors as frictional lags in the soil column, water content, and by overburden.

Compaction Processes

A considerable body of information has been developed in the field of soil mechanics to describe the physical and other properties of different types of soils and the behavior of these soils under varying conditions of overburden and presence of water. Literature on soil mechanics has been thoroughly reviewed in order to develop analogies that may exist between "pure" soils and the heterogeneous mass of materials found in landfills. Applicable theories of consolidation are extensive and have been condensed and summarized herein.

Soil Properties

A soil mass is commonly considered to consist of a network or skeleton of solid particles enclosing voids or interstices of varying sizes.

The voids may be filled with air, water, or partly with air and water. Three volume ratios are used to describe the interrelationships between solid, liquid, and air in the soil mass. These are: porosity, the ratio of the voids volume to the total volume of the mass; void ratio, ratio of volume of voids to volume of solid; and degree of saturation, ratio of volume of water to volume of voids. Two weight ratios are useful in describing soil masses on this basis: water content of a sample is defined as the ratio of weight of water to weight of dry solid matter; unit weight or weight per unit volume can be defined in terms of the soil mass as a whole, the unit weight of solids, and the unit weight of water.

Structure of Soil Aggregates

Three structural types of soils exist which may be defined to illustrate the heterogeneity expected in refuse. Single-grained structure is observed in coarser materials having little or no cohesion, such as sand and gravel. Single-grained soils may have a wide range of porosities depending on the manner in which the material is aggregated. Honeycomb structure occurs in materials fine enough to have cohesion, i.e., particles small enough to be affected by intermolecular cohesion. Soils with a honeycomb structure are porous and contain large voids. Flocculent structure occurs only in fine soils and is derived from colloidal suspensions which have been destabilized, resulting in formation of a honeycomb structure made up of small soil particles.

Effects of Pore Water on Soil Aggregate

The melange of inorganic and organic materials in a landfill responds to pore water with significant, often dramatic, changes in soil column behavior. Pore water can generate the solution of materials from the solid matrix of the soil, resulting in the eventual transport of materials from the source zone and enhancing permeability, or plugging pore passages and reducing permeability. As a result the properties of landfill materials are expected to depend to a large degree on the amounts of pore water in the soil. From the viewpoint of biological degradation, pore water has the additional positive effect of accelerating the development of voids.

Stress-Strain Characteristics

Stress-strain relationships are the mechanical properties of soils which determine the settlement that a given overburden will cause. The simplest of these relationships is for elastic materials in which stress and strain are proportional and independent of time. Stress-strain relationships for soils are not linear and change over time; also, soils are acted upon by lateral pressures due to overburden and other loads supported by soil.

Analogically, landfill material may be considered as a skeleton of solid grains enclosing voids which may be filled with gas, liquid, or a combination of gas and liquid. As such matter is placed under stress in such a way that its volume is decreased, three factors may contribute to compression: compression of solid matter; compression of water and air in the voids; and escape of water and air from the voids. Under load, a decrease in the volume of soil mass is probably due entirely to escape of water from pores and/or compression of gas in pores. With the compressible types of materials often found in landfills, some of the volume decrease may relate to compression of the matter itself in addition to escape of pore water or compression of gas in the pores. However, compressibility phenomena in a landfill, because of the heterogeneous nature of the material, are primarily a function of the extent to which landfill elements can shift positions. As compression progresses, a point is reached where the decrease in void volume must result in the escape of pore water. If the material under compression has a low coefficient of permeability, compression may occur as a gradual process over a time period prolonged by the slow escape of water.

Compression of Sand and Clay

Sands and clays represent the behavioral boundary conditions of most materials found in landfills. Sand is generally unsaturated and its stress-strain characteristics depend primarily on the relative density of the material and to a much lesser extent on particle shape and size. In clay essentially two phenomena take place which cause a long lag in subsidence: escape of pore water, limited by permeability controlling the flow of water; and plastic lag, due to plastic action of water adsorbed near grain to grain contacts or points of nearest approach to contact.

A major portion of the compression in sands occurs almost instantly after a load is applied and is affected little by the degree of saturation of the sand. The time lag during compression of sand is largely frictional and is caused by successive, irregular, localized build-up and breakdown of stresses in grain groups.

Compression cannot occur instantly or rapidly in clay because the pore water cannot escape immediately. Hydrostatic pressure, developed in the pore waters of clay by imposition of an overburden on the clay, forces the pore water out. As pore water moves out, grains of clay move closer together, allowing subsidence to occur and increasing the resistance of the soil mass to outflow.

Summary

Soil mechanics provides a framework for considering the probable phenomena which cause subsidence in landfills. Refuse, compared with most soils, has heterogeneous and low-density characteristics upon emplacement and initial compaction. Biological decomposition adds to voids resulting in the weakening of many of the structural elements in a landfill mass, facilitating the reformation of the material by subsidence under an overburden. In the interacting sequence of events causing subsidence in a landfill, the above theoretical concepts lead to the following sequence of events in the subsidence of landfills:

(1) An increase in the relative density of the refuse material is effected immediately by compaction of the material upon emplacement.

(2) A gradually increasing rate of biological decomposition occurs over time, enhanced by the autocatalytic increase of microorganisms, by ingress of water to the fill, and by increasing temperature.

(3) Development of voids filled with gases and water occurs as biological decomposition progresses, leading to a decrease of density and additional subsidence of the weakening structural elements of the landfill.

(4) Continued iteration of decomposition, subsidence, decomposition, etc. takes place to an extent that ultimately a rigid structural

skeleton is formed or that a saturated soil condition evolves in which the escape of water becomes time dependent and limited. In either case, increased density may result.

LABORATORY PROCEDURE

Mixtures of refuse were prepared using different amounts of different sizes of paper, garbage (fresh green vegetable cuttings), garden wastes (leaves, etc.), noncombustibles (metal, glass, ceramic), and sand as an inert filler. Each of these components was shredded into two sizes (1/2-inch and two-inch) designated as fine and coarse. Three types of refuse were prepared on the basis of high, medium, and low paper content, and each of these types was subtyped as fine, mixed, or coarse as related to the sizes of stock material used (fine, coarse, or a 50-50 mixture of each). The composition of the nine mixtures is shown in Table II-12. The 51 test cells (each approximately 10 inches high by eight inches in diameter) developed from the nine mixtures as follows:

1. A series of preliminary compaction tests was conducted with the dry refuse to determine maximum density of the refuse cells and their porosity at maximum density.
2. Based on the porosity of each stock mixture, the water quantities required to establish 65 percent and 100 percent saturation were established.
3. Eighteen aerobic and duplicate anaerobic test cells (36 total) were prepared, nine of each type in the dry state and nine of each type at 65 percent saturation at time of preparation.
4. Nine cells (one from each stock mixture) were prepared at 100 percent saturation at time of preparation.
5. After about 120 days of monitoring, six new cells were set up, all of which contained coarse-size material. Two each of the six units were prepared with low paper content, two with medium, and two with high paper compositions. Three were set up as anaerobic and three as aerobic cells; all were set up at a saturation level of approximately 20 percent at time of preparation.

Synthetic refuse mixtures were prepared using paper, garbage (vegetable greens), garden wastes (green leaves, wooden stems, and grass), metal, glass, ceramics, rags, plastics, leather, and sand in three discrete mixtures and with three particle size ranges. The principal variant in the composition of the mixtures was the paper content, which was selected at 20, 30, and 60 percent levels. All the above refuse components were shredded into two sizes, 1/2-inch and two-inch. Three categories of high, medium, and low paper content refuse were prepared using: (1) all 1/2-inch materials (fine); (2) all two-inch materials (coarse); and (3) a 50-50 mixture of 1/2-inch and two-inch materials (medium). Thus, on the bases of size and composition, nine different types of synthetic refuse mixtures were developed.

The following is a brief description of the components used in the refuse mixtures:

(1) Paper: coarse paper was prepared by shredding laboratory paper towels to a size of approximately two inches. The fine paper material consisted of the waste materials from the punching of computer cards.

(2) Garbage: fresh lettuce, cabbage, and celery mixtures constituted the garbage fraction of the experimental refuse. These items were cut to the coarse and fine sizes in the laboratory.

(3) Garden Waste: a mixture of green leaves, wooden stems, and grass comprised the garden waste. These materials were cut in the laboratory to the fine and coarse sizes.

(4) Metal, Glass, and Ceramics: two sizes of nails, small and large pieces of broken glass, and pottery were mixed in equal portions to form fine and coarse stock mixtures of these noncombustibles.

(5) Rags, Plastics, and Leather: leather clippings and shredded polyethylene sheets of various thicknesses were mixed together in two sizes to develop stock mixtures of this component.

(6) Inert Soil: a dry sand was added as inert soil in all of the refuse mixtures.

The composition and analysis of the nine experimental refuse mixtures are summarized in Table II-12. The principal variants in the composition of the high, medium, and low paper refuse mixtures were (besides paper) garbage, garden waste, and metal-glass ceramics. The garbage and garden waste contents varied from 10 percent in the high paper mixture to 30 percent in the low paper mixtures. The metal, glass, and ceramic content varied from 10 percent in the high paper mixtures to 20 percent in the medium and low paper mixtures. On a weight basis, the water content of the mixture varied from 13 percent in the high paper mixture to 34 percent in the low paper mixture. The volatile matter content varied from 81 percent in the high paper mixture to 58 percent in the low paper mixture.

The estimated carbon and nitrogen contents of the experimental refuse mixtures are summarized in Table II-13. The high paper mixture was found to contain 34 percent carbon and 0.4 percent nitrogen; the medium paper mixture 26 percent carbon and 0.7 percent nitrogen; and the low paper mixture, 23 percent carbon and 0.9 percent nitrogen. Therefore, the C/N ratio varied from over 90 percent in the high paper to approximately 25 percent in the low paper.

Experimental Test Units

A graphical representation of the two types of test units used in this experiment is shown in Figure II-7. Each test unit consisted of a PVC pipe of a nominal eight-inch inside diameter and a 12-inch length. A perforated 1/2-inch ID PVC pipe of 13-inch length was placed in the center of the larger pipe. The 1/2-inch pipe was used as a guiding shaft for compaction operations as well as for supplying air to the aerobic units. In the decomposition studies, a thermometer was placed in the center pipe to permit monitoring of the temperature variations in the decomposing refuse materials. A 10-pound concrete weight, cast to fit inside the eight-inch PVC pipe, was placed on top of the refuse material in each test unit. Measurements from the top of the center pipe to the top of the weight provided a measure of subsidence of the refuse in the test unit under this condition of surcharge. Each unit was held in a metal container and supported on a wire mesh which allowed the leachate to waste.

Compaction of Refuse Cells

Two sets of refuse compaction experiments were conducted; the first set established the maximum densities and minimum porosities of the nine types of refuse materials, the porosities providing a base for adjustment of the water content of the stock materials; and the second set, simulated the degree of compaction realized by the movement of bulldozers or other equipment over the fill site. The second set of compactions was conducted after adjustment of moisture content of the refuse mixtures and prior to decomposition studies.

A wide variety of equipment is used for refuse and earth-moving operations at fill sites, commonly used pieces of equipment being crawler tractors and wheeled scrapers. A typical scraper used in large landfill operations is the TEREX TS-32 scraper. A TEREX TS-32 scraper can produce a static stress of 70 psi on a contact area of 22 by 33 inches. If it is assumed that refuse is compacted in three-foot lifts and that surface stress is distributed downward at a 45-degree angle, then compaction stress at the middle plane of the refuse lift would be approximately 13 psi. This value was considered as the average static stress that can be applied in the field during the construction of a sanitary landfill. A compaction stress of 13 psi was applied to the tested refuse in the laboratory by the impact of 57.4-pound weight falling freely from a height of 21 inches above the refuse surface. If it is assumed that the falling weight would come to complete rest one second after initial contact with the refuse material, this procedure would also produce an approximate static compaction stress of 13 psi.

The first set of compaction experiments was carried out using the nine stock materials (high, medium, and low paper stock, each in coarse, medium, and fine sizes) with no water addition. The eight-inch experimental test units were filled with hand-packed refuse to a height of five inches. The refuse was compacted by the dropping weight and the depth of the refuse was recorded after each drop. Compaction continued until two successive drops produced no apparent change in the refuse height. At this point, compacted refuse was considered to be in equilibrium with the stress applied by the dropping weight. The number of drops required to establish equilibrium for each of the nine stock mixtures was used later in preparation of duplicate cells of each mixture (18 in all), one set of which was used for aerobic decomposition studies and the other for anaerobic studies.

After the number of weight drops to establish maximum density was obtained, the compacted cells were weighed and then immersed in a known water volume in a graduated 10-liter container. The observed increase in water volume was recorded as the volume of refuse solids. With this information it was possible to determine the porosity and the unit weight of each of the compacted stock mixtures of refuse.

It was possible using the porosities of each type of dry compacted stock mixture to estimate the amounts of water required to achieve selected degrees of saturation. Actual measurements, made after compaction to equilibrium, of the set of nine stock mixtures at various levels of water addition showed that a maximum unit weight of wet refuse corresponded to about 65 percent water saturation. This level of saturation was selected in the preparation of two sets of partially saturated cells, nine for aerobic and nine for anaerobic decomposition studies.

In addition to the 18 dry and 18 partially saturated cells, nine additional cells were prepared by saturation of each of the stock mixtures.

The compaction procedures used in preparation of the above 45 dry, partially-saturated, and saturated refuse cells (second set of compaction experiments) are as follows:

(1) Sufficient quantities of each of the stock refuse mixtures were transferred to fill about 5 inches of the 8-inch ID polyvinyl chloride pipes.

(2) The compaction weight was dropped the number of times determined in the first set of tests for the specific refuse mixture to attain maximum compaction.

(3) Steps (1) and (2) were repeated until the compacted refuse reached a height of 10 inches in the test unit.

(4) Each experimental test unit was weighed before and after the compaction operation and the weight of refuse content, obtained by the difference, was recorded.

(5) Each unit was placed on top of a wire mesh in a separate container. A thermometer was inserted in the central pipe and the ten pound concrete weight was fitted on top of the refuse in the test unit.

(6) All containers were transferred to a constant temperature room with adequate ventilation to prevent accumulation of hazardous gases resulting from decomposition of refuse materials. The room temperature was maintained first at 25°C (77°F) and later at 30°C (86°F) (to accelerate the decomposition process).

(7) All test units were ventilated by tubes from the units connected to a suction pump outside the constant temperature room. In addition the aerobic test units were connected to an air supply line which was connected to a compressed air unit outside the constant temperature room. Compressed air was blown into the aerobic units for several hours every other day. (The rate of flow was not recorded.)

SUBSIDENCE DURING DECOMPOSITION

The compacted refuse cells were allowed to decompose and subside in the constant temperature room over a period of nearly 200 days. Records of weight, temperature, and subsidence of the decomposing refuse were made during the course of this period. Subsidence was measured as the drop of the weight in relation to the central pipe in the experimental test units. Leachates were drained from the units before weight measurements were taken. At first, records were kept daily, eventually the interval was decreased to twice a week and then to once a week toward the end of the monitoring period.

After about four months of monitoring, some of the units containing refuse with 60 percent paper showed little progress in subsidence. For this reason these units were replaced by six new cells, all of which contained coarse-size material, 30 percent water (weight basis). Two of the six units each were prepared with low paper content, two with medium, and two with high paper compositions. Three units were established as anaerobic cells and three as aerobic cells.

Consolidation of Decomposed Refuse

In this test experimental stage, the decomposed refuse cells were systematically subjected to confined compression tests in order to determine stress-strain characteristics of the refuse material. At this stage of the experimentation, the refuse cells had been allowed to decompose for seven months. In the case of the low paper cells, the level of decomposition was less. The consolidation tests were conducted using the beam apparatus shown in Figure II-8. The apparatus was designed for operation with preconsolidated refuse samples 8 inches in diameter and 4 inches thick. These dimensions were considered the minimal acceptable for testing of slices of the refuse cells inasmuch as the coarse particles were adjusted to a 2-inch size and the composition of the cells was relatively heterogeneous. As shown in Figure II-8, the compression machine was basically a second degree lever with a ratio of 10:1 for the applied load. With exception of the loading hook, tension rods with turnbuckle, the compression rod, and the stiffeners, the unit was fabricated with wood.

The following is a brief description of the procedures used in carrying out the consolidation test:

(1) The refuse sample was preconsolidated overnight by increasing the weight on each refuse cell from 10 to 90 lbs, i.e., from 30 to approximately 270 lb/sq ft. The stress of 270 lb/sq ft is approximately equal to the stresses imposed on the top refuse layer in a landfill due to the final fill cover.

(2) Measurements of the sample height and weight were recorded before and after preconsolidation.

(3) A 4-inch slice of each refuse cell, and the length of PVC pipe holding the slice intact, was sawed from the total refuse cell; in this manner an "undisturbed," preconsolidated slice of each cell was obtained for the consolidation tests.

(4) The sliced sample was then placed on the sample base of the compression apparatus and consolidated by progressively increasing loads.

(5) The first load applied to the refuse sample was the dead weight of the mechanical lever, which produced a stress of 1,257 lb/sq ft at the refuse surface. Subsequent load increments produced stress increments equal to 600 to 800 lb/sq ft of stress.

(6) Settlement of the sample was recorded after approximately one hour of application of each load and then the additional load was applied. One hour was used because the majority of the compaction had taken place at that time.

Consolidation progressed at an extremely low rate after the first few seconds of loading. Because of this phenomenon, only a limited number of time-deformation curves were developed; most of the later tests were monitored by making a single observation of settlement after one hour. Rebound was not measured.

RESULTS

A synthesis of all results obtained in the various phases of the study is presented in this section. Detailed data sheets for each experimental area of the study are presented in Tables II-14 to II-27.

Compaction of Refuse Cells

The results of the first set of compaction tests are presented in Figures II-9 through II-12. Figure II-9 illustrates the relationship between density (unit weight) and unit energy input (weight drops). From five to seven unit energy inputs of 1,200 lb-inch were required to obtain maximum unit weights in the unwetted test cells. The greatest unit weights were achieved in cells with the lowest paper content (28 to 42 lb/cu ft) and in cells with fine-size refuse particles (29 to 42 lb/cu ft), as shown in Figures II-9 and II-10. The least unit weight value (18 lb/cu ft) was obtained in the cell containing 60 percent paper and coarse particle sizes.

Figure II-11 indicates the relationships between porosity, composition, and paper content for the nine stock mixtures after compaction to maximum dry density. The porosity relationships were increased to the unit weight relationships; the cells containing low paper content and fine-size particles had the lower porosities. The porosities of the test cells varied from 35 percent, for the cell with fine-size particles and 20 percent paper, to nearly 70 percent, for the high-paper coarse-particle cell.

The effect of water addition on the unit weight of the compacted refuse is shown in Figure II-12. Maximum unit weights varied from 60 lb/cu ft for the 30 percent paper, coarse-particle cell to under 50 lb/cu ft for the 20 percent paper, fine-particle cell. Maximum unit weights occurred at levels of, or in excess of, 65 percent saturation.

Decomposition and Subsidence

Observations were made on the time variation of weight loss and subsidence for the 45 refuse cells in the constant temperature room over a period of study. Unit weight change has been estimated from these data on the basis of the following formula:

$$\gamma_f = \gamma_i \left[1 + \frac{S_D}{100(1-\frac{W_f}{W_i})} \right] \qquad \text{(II-1)}$$

where:

γ_f = final unit weight, lb/cu ft

γ_i = initial unit weight, lb/cu ft

S_D = subsidence due to decomposition, percent

W_f = final weight of cell, lb

W_i = initial weight of cell, lb

It is assumed in Equation II-1 that no water is lost as subsidence occurs, a situation which did not obtain in the saturated and partially-saturated cells. For this reason final unit weight observations presented subsequently represent approximate estimates of the true final unit weight of the saturated and partially-saturated cells after decomposition.

Weight Loss and Unit Weight Change

Weight loss observations for the 45 refuse cells are summarized in Figures II-13 to II-17 for the aerobic-dry (A/D), anaerobic-dry (An/D), aerobic - 65 percent saturated (A/65), anaerobic - 65 percent saturated (An/65), and anaerobic saturated (An/S) cells, respectively.

The greatest weight losses with decomposition in the A/D cells (Figure II-13) were observed with the low-paper cells and varied from 20 to 33 percent. The least weight losses in the A/D cells were about 15 percent and occurred in the high-paper cells. Weight losses in the An/D cells (Figure II-14) were greatest in the low-paper cells (12 to 20 percent) and least in the high-paper cells (<10 percent). Generally the percent of weight losses were greater after decomposition in the A/D cells than in the An/D cells.

The most significant weight losses in the A/65 cells (Figure II-15) was observed in the low-paper cells, the weight loss varying from 33 to 50 percent. The least weight losses in the A/65 cells were observed in the high-paper cells. Overall weight losses for the A/65 cells were 50 to 100 percent greater than observed with the A/D cells. The greatest weight losses observed in the An/65 cells were found in the low-paper cells, the weight losses were 35 to 40 percent, and the least weight losses occurred in the high-paper cells (Figure II-16). As a rule weight losses in the An/65 cells were 15 to 25 percent less than that observed in the A/65 cells.

Figure II-17 illustrates the weight loss observations for the An/S cells. It is apparent that the greatest weight decreases (40 to 50 percent) occurred in the low-paper cells and the least weight losses in the high-paper cells. The rate at which weight loss was incurred was much greater initially (first 20 days of the experiment) in the An/S cells than in all of the other cells; after the initial 20-day period, the rates of weight loss in the An/S cells were similar to those in the 65 percent saturated cells.

It can be concluded from the weight loss data that the greatest weight losses occurred in the low-paper cells, varying from 12 percent in the dry cells to 50 percent in the saturated cells. Weight losses were generally greater in the aerobic than in the anaerobic cells by 10 to 20 percent, and tended to increase with increasing particle size.

The change in unit weight of a refuse cell is a function of the degree of compaction which occurs in the structure of the fill material, and is related to the degree of breakdown of the structure of the fill material and the degree to which water can escape from the fill. The decomposition studies were conducted with an overburden of 30 lb/sq ft. Unit weights were estimated from weight loss and subsidence data using Equation II-1 and are presented in Figures II-18 to II-22.

Unit weight changes in the A/D cells are presented in Figure II-18. The greatest changes occurred in the low-paper cells: about 15 to 25 percent increases to final unit weights between 45 and 50 lb/cu ft. The higher-paper cells tended to decrease slightly in unit weight to final levels between 20 and 30 lb/cu ft. Unit weight changes in the An/D cells are presented in Figure II-19. Trends in unit weight changes in the An/D cells were similar to those in the A/D cells in that the greatest increases were in the low-paper cells.

Figure II-20 illustrates unit weight changes in the A/65 cells, which did not follow the trends of increasing over time as observed in the dry cells. With exception of the fine-size, 20 percent paper cell (which increased 20 percent in unit weight), five to ten percent decreases were observed in the unit weights of the A/65 cells. An unverified explanation for this phenomenon is the loss of water as leachate during the decomposition process. An analogous pattern of unit weight change was observed in the An/65 cells (Figure II-21).

Unit weight changes in the An/S cells are presented in Figure II-22. Generally minimal weight changes occurred after initial unit weight decreases from 10 to 25 percent. The initial weight losses are believed to be attributable to water losses from the cell as leachate. The final unit weights of the An/S cells varied from 55 to 65 lb/cu ft and, at these levels, the An/S cells were more dense than the partially-saturated cells.

The unit weight estimates in Figures II-18 to II-22 can be summarized as follows:

(1) There was a general increase in final unit weight with increasing water content.

(2) The highest unit weights were observed with the low-paper cells and the differences in unit weight between low-paper and other cells decreased as degree of saturation increased.

Subsidence Rates

The day-to-day observations of subsidence in the five sets of test cells are presented in Figures II-23 to II-27; final subsidence rates from these observations are presented in Figures II-28 to II-30. Isometric drawings of the ultimate subsidence levels (end of 200-day test period) in the five sets of cells are presented in Figures II-31 to II-35.

The day-to-day observations of subsidence in Figures II-23 to II-27 show essentially four modes of subsidence to be occurring:

(1) High initial rate of subsidence followed by a diminished rate or total cessation of subsidence;

(2) Low initial rate followed by increasing subsequent rate;

(3) Steady high rate of subsidence for the duration of the experiment; and

(4) Steady low rate of subsidence for the duration of the experiment.

The first case is exemplified by the A/D cells comprised of coarse materials and containing 30 to 60 percent paper (Figure II-23), in which a high initial rate of subsidence dropped off to minimal levels after approximately 100 days of study. The second case is exemplified by several A/65 cells (Figure II-25) in which the rate of subsidence increased as the experiement progressed. Case (3) is exemplified by the A/D cell containing coarse-size materials and 20 percent paper (Figure II-23), where subsidence proceeded at a significant rate for the entire study. The fourth case is typified by the subsidence rates of the fine and mixed-size, 60 percent paper cells.

Because of the several modes of subsidences discussed above, it is apparent that the rate of subsidence of a cell may vary widely with composition, particle size, degree of biodegradability of material, etc. As a basis for comparing the relative rates of subsidence of the different types of cells it was necessary to select a common reference time in which rates could be determined from curves in Figures II-23 to II-27 for comparative purposes. The time frame selected for this purpose was the last 20 days of observations; this selection was made on the basis that the six months of experiements leading to the last 20 days of subsidence observations would provide sufficient time for development of microorganism cultures and the initiation of decomposition of the biodegradable material in the cells. The percent rate of subsidence (annual basis) during the last 20 days of observation in Figures II-23 to II-27 are illustrated in Figures II-28 to II-30.

The average annual subsidence rates for all cells with fine-size refuse materials are shown in Figure II-28. There was a generally decreasing trend in the value of the subsidence rate as the paper content increases, viz., from 45 to 75 percent per year at low paper content to five to ten percent per year at high paper content. At high paper content, the subsidence rates for all five types of cells with fine materials tended to converge. At low paper content, the highest rates of subsidence (75 percent per year) were observed for the An/S and A/65 cells and the lowest rate (45 percent per year) for the An/D cell. In all cases but for the An/65 cells, the subsidence rate at 30 percent paper content was much lower than the rates for the same respective cells at 20 percent paper content.

Average annual subsidence rates for all cells with mixed-size refuse materials are shown in Figure II-29. The same trend of decreasing subsidence rate with increasing paper content was apparent for the mixed cells as it was for the fine cells. The rates decreased from 50 to 80 percent per year at low paper content to five to 20 percent per year at high paper content. There was a lesser convergence of the subsidence rates at high-paper content with the mixed cells than with the fine cells. As a general rule for all paper contents, the rates decreased in the following order: An/D > An/S > A/65 > An/65 > A/D. That the subsidence rates for the An/D cells were greater than for all other cells was an unexpected result; other than this anomaly, the general trend of increasing subsidence rates with increasing degree of saturation was observed for the mixed cells as it was for the fine cells. In all cases the general span of rates for the mixed cells was similar to that for the fine cells.

The average annual subsidence rates for all cells with coarse-size refuse materials are shown in Figure II-30. There was a generally decreasing value of the subsidence rate as the paper content increased, as was observed for the fine and mixed cells. The rate decreased from 50 to 85 percent per year at low-paper content to eight to 20 percent per year at the high-paper content. The rates decreased in the following order over all paper content: A/D > A/65 > An/S > An/D > An/65. In all cases the rates at 30 percent paper content were less than the rates for the same respective cells at the 20 percent paper content. There is a broader range of rates for the coarse cells at all paper content than was observed for the mixed or fine cells.

It can be concluded that there is a trend of decreasing rates of subsidence as the paper content increases; the rates at 60 percent paper content are one-third to one-fifth those at the 20 percent paper content. The highest subsidence rates were observed generally with the An/S and A/65 cells. The rates of subsidence tend to converge toward a value of about 10 percent per year as the paper content increases to 60 percent.

Ultimate Subsidence

Ultimate subsidence observations (at the end of the 200-day study period) are presented isometrically in Figures II-31 to II-35 for each of the five types of cells. The isometric drawings permit the representation of the ultimate subsidence surface as the function of refuse size and paper content. The ultimate subsidence surface for the A/D cells is shown in Figure II-31; the surface decreases as refuse size decreases and as paper content increases. The ultimate subsidence response surface for the An/D cells is shown in Figure II-32; the surface decreases as refuse size increases or decreases from the mixed size and as the paper content decreases. Figure II-33 shows the ultimate subsidence surface for the A/65 cells. The greatest subsidence was observed at the 30 percent paper level for the coarse and mixed sizes, and at the 20 percent paper level for the mixed size. The subsidence surface decreases from the 30 percent paper level sharply to the 60 percent paper level. The ultimate subsidence surface of the An/65 cells is shown in Figure II-34. The surface of ultimate subsidence decreases from coarse to mixed and from fine to mixed and as paper content increases. Figure

II-35 shows the ultimate subsidence surface for the An/S cells; little trend can be seen in the surface with size variation, but the surface decreases with increasing paper.

The ultimate subsidence observations after 180 days of decomposition showed that subsidence levels decreased with increasing paper content but showed no consistent trend with size of refuse material. In evaluation of these observations it should be noted that time constraints precluded tracking the degree of decomposition which had taken place in the cells or of the amount of leachate which had been lost from the cells over the experimental time period. Nonetheless, the results presented above verify that the higher the garbage content or the lower the paper content in a composite refuse, the greater will be the subsidence due to decomposition processes.

Consolidation Studies

The approach to the consolidation studies was to ascertain what mode of consolidation (time-dependent and/or pressure-dependent) took place during surcharging slices of the test refuse cells and to define what parameters could be used to describe these phenomena.

Time-Deformation Curves

Time-deformation curves were prepared for a series of samples with the beam consolidation apparatus to determine the time dependency of refuse consolidation and to what extent analogies could be considered between refuse consolidation and sand and clay consolidation. Time-deformation curves were developed for samples having the following characteristics: An/S, 30 percent paper, and coarse-size materials; An/25 (percent saturated), 20 percent paper, and coarse-size materials; and A/15, 60 percent paper, and coarse-size materials. Time-deformation curves for each of these refuse mixes are shown in Figures II-36 to II-38. The pattern of increasing pressures used for the studies was initiated with a stress of 1,260 lb/sq ft (beam dead load) and increased in varying increments to maximum stresses in the range of 4,000 lb/sq ft. Observations were made at each pressure increment for durations in excess of 15 minutes.

The general pattern of the time-deformation curves for all three types of refuse and for most of the pressure increments can be described as an initial sudden compaction occurring in the first 0.1 minute, after which a gradual compaction continued to take place. The gradual subsidence taking place thereafter can be described by the equation:

$$C = k_1 \ln (t/t_o) \qquad \text{(II-2)}$$

where: C = compaction

k_1 = slope of each time-deformation curve

t_o = 0.1 minute

t = time, minutes

A phenomenon typical of sand is that initial compaction occurs in less than 0.1 minute. However, the cells did not appear to attain maximum compaction levels in time periods of less than 10 minutes, thus exhibiting a behavior atypical to sand.

The time-deformation curves in Figure II-36 manifest several types of behavior. A significant initial compaction took place as the initial pressure increment was added and did not recur as additional increments were imposed. During the time interval in which the cell was consolidating under the first increment, the slope of the time-deformation curve approached a steady exponential rate which appeared to be maintained as pressure increments were added. The sample did not approach equilibrium during the 15-minute intervals in which each increment was added.

In contrast with the curves shown in Figure II-36, the results presented in Figure II-37 indicate that the rate of settlement of the sample decreased significantly with increasing pressure. After 1-1/2 hours of observations at a pressure of 3,285 lb/sq ft, the rate of settlement was about one-seventh that at the pressure increment of 1,260 lb/sq ft.

The third set of time-deformation curves (Figure II-38) illustrates neither the slackening rate of settlement of the cells described in Figure II-37 nor as great a rate of settlement as the results for the cells shown in Figure II-36.

The time-deformation curves provide an insight to several aspects of the behavior of consolidating refuse materials. It is apparent that the refuse cells do not consolidate in a manner uniquely identifiable with the settlement of sand or clay under similar circumstances. However, the time-deformation curves of the refuse cells did resemble sand in the type of rapid initial adjustment of unit weight of the cells; and resembled clay in the type of continuing plastic subsidence, observed as the testing progressed. It is unknown whether the latter behavior was related to the escape of pore water and relief of an excess hydrostatic pressure or to the continuing localized buildup and breakdown of stresses in materials in the cells, or a combination of both of these or other factors. However, it was apparent from these studies that a significant fraction of the cumulative settlement took place within the first few minutes after application of pressure and that the cells tended to assume a pseudo-equilibrium rate of settlement after the first few minutes of consolidation which tended to diminish as the pressure increment increased. Because of the pseudo-equilibrium rate of settlement which occurred as time and pressure increased, it was assumed that the stress-strain studies could be carried out by making single observations of the degree of settlement which had occurred after approximately one hour of consolidation.

Stress-Strain Studies

Stress-strain data were developed for the 45 test cells described in the decomposition studies, using as strain measurements the settlement occurring in the test cells after one hour on the beam consolidation apparatus. The results of the stress-strain observations for each of the five sets of refuse cells are summarized in Figures II-39 to II-43, respectively. The data were developed using the beam dead weight stress of 1,260 lb/sq ft as the base stress, and five pressure increments (added sequentially to a maximum stress level of about 4,000 lb/sq ft). The application of the base stress of 1,260 lb/sq ft represented a positive pressure increment of 990 lb/sq ft over the preconsolidation stress of 270 lb/sq ft imposed on the test cells, and caused a sudden initial compaction of the test cells (Figures II-39 to II-43).

It can be seen from the linear relationships (semilogarithmic basis) in Figures II-39 to II-43 that the initial compaction effected by the base stress was disproportionately larger than compaction affected by subsequent stress increments. The disproportionate initial compaction indicates that imposition of the base stress caused a significant adjustment of the unit weight of the test cells toward a unit weight at which the cell was in or approached equilibrium with the base stress. In contrast with initial compaction, the secondary compaction (taking place as the stress is increased gradually from base stress) occurs in a manner which permits the cell to adjust itself continually toward a unit weight in equilibrium with the compaction stress applied.

A basis for evaluating the factors affecting initial compaction was established by an analysis of the strain at the base stress of 1,260 lb/sq ft vs the paper content of the cells. The results of this evaluation are plotted in Figure II-44, wherein two groups of initial compaction values can be identified, one group consisting of the initial compaction data for saturated and partially-saturated cells, and the other for the dry cells. Initial compaction levels for the dry cells varied from averages of 20 percent at 60 percent paper content to 27 percent at 30 percent paper content, to 23 percent at 20 percent paper content. The average initial compaction levels for the saturated and partially-saturated cells was 29 percent at 20 and 60 percent paper content and 32 percent at 30 percent paper content. Thus it can be concluded that under the experimental conditions of this study, the water content and the paper content of the cells were factors in the process of initial compaction.

The relationship between unit weight and initial compaction was also evaluated in the stress-strain studies. Figure II-45 illustrates the theoretical relationship, assuming no loss of water from the cell upon initial compaction:

$$C_i = 100 \frac{\gamma_f - \gamma_i}{\gamma_i} \qquad \text{(II-3)}$$

where: C_i = initial compaction, percent

γ_f = final unit weight, lb/cu ft

γ_i = initial unit weight, lb/cu ft

The values of these parameters will vary widely from one type of material to the next, and initial compaction of a refuse of known initial unit weight can be predicted only after field or laboratory testing. The unit weights achieved after compaction of the 45 test cells under a stress of 1,260 lb/sq ft are shown in Figure II-46, where it may be observed that unit weight at a stress of 1,260 lb/sq ft varied between 80 and 120 lb/cu ft for the partially-saturated and saturated cells, but varied between 20 and 100 lb/cu ft for the dry cells.

Secondary compaction has been defined previously as that strain occurring subsequent to initial compaction and as depicted by the semi-logarithmic relationship between strain and pressure in Figures II-39 to II-43. It must be assumed that secondary compaction occurs relatively independently of initial compaction. On this premise the strain scales delimiting the portion of the stress-strain curves in Figures II-39 to II-43 attributable to secondary compaction were normalized to 100 percent scale so that secondary compaction could be expressed as a percent of full sample height independent of initial compaction. Secondary compaction can then be described by the equation:

$$C_s = k_s \ln (p/p_o) \qquad \text{(II-4)}$$

where:
C_s = secondary compaction, percent
k_s = secondary compaction constant, units of percent
p = stress, lb/sq ft
p_o = base stress (1,260 lb/sq ft in this study)

Equation II-4 has been used to establish the secondary compaction constant, k_s, for all of the linear relationships shown in Figures II-39 to II-43, the k_s value for each of these cells is presented in Table II-28.

The secondary compaction constants (k_s) presented in Table II-28 vary from 12.9 to 17.1 percent for the A/D cells, and average 14.4 percent. This parameter varies from 11.2 to 22.5 percent for the An/D cells and averages 13.7 percent; k_s varies from 12.6 to 17.3 percent for the A/65 and An/65 cells and averages 14.7 percent; and k_s varies from 3.2 to 15.2 percent for the An/S cells, averaging 13.4 percent. On an overall basis the secondary compaction constant averages 14.3 percent for all five types of cells, and it is apparent from consideration of the average values of the constants for each of the five sets of cells that there is little departure from the overall average in the entire set of observations. For this reason, the value of 14.3 percent was selected as the secondary compaction constant to be used in conjunction with application of Equation II-4.

PREDICTION OF LANDFILL SETTLEMENT

Mechanisms in Settlement

The foregoing section has provided the bases for describing three discrete mechanisms active in the process of settlement in a landfill, viz., decomposition, initial compaction, and secondary compaction. The functional independence of each of these mechanisms from the others in the course of the analysis has been assumed but not verified. The assumption that each mechanism is independent functionally of the others allows each mechanism to be treated as a unit process occurring without regard to sequence and as a separate element in the mathematical description of landfill settlement.

There are several implications from the findings of the foregoing section on these mechanisms. Decomposition has been described as a time-dependent but not pressure-dependent mechanism. The rate of progress of settlement due to decomposition is assumed to vary not with the age of the fill but with the age of the lift in the fill. The degree of subsidence due to initial and secondary compaction was treated as primarily pressure-dependent and due to imposition of an overburden. In normal landfill operation the overburden is increased periodically with the addition of a new lift; thus over a period of time an additional amount of subsidence is expected from the same lift due simply to the increasing overburden pressures of the overlying lifts. In this context a landfill can be described as a multilayer amalgam of individual layers of decomposable and compactable material, each layer with a specific history of accumulation of overburden and a specific age. Each of the mechanisms, reviewed in detail below, must be evaluated in terms of how it contributes to overall settlement in a fill.

Decomposition

The laboratory studies have demonstrated the transient character of decomposition as a factor in settlement, the rate of readily degradable substrate decreasing to lower levels as less readily degradable substrates are successively used.

The transient effect of decomposition on the rate of settlement has often been observed in the field and many cases have been cited in the literature where a completed fill has undergone a rapid rate of settlement in its first year and a rapidly diminishing rate of settlement in the second year. These observations provide a basis for establishing the time variation of the rate of subsidence of a lift due to decomposition which reflects an increasing rate of settlement during the early portion, and a decreasing rate during the later portion, of a two-year period. Figure II-47 shows the pattern of variation selected in this study as a basis for placing a time scale on the rate of subsidence. The relationship shown in Figure II-47 depicts the subsidence rate as a function of k, where k is defined as the average annual rate of subsidence observed at 180 days in the laboratory studies and presented in Figures II-28 and II-30. The subsidence rate depicted in Figure II-47 increases to a maximum value of 1.0 k at six months, then decreases to a value of 0.1 k at 12 months, and to zero at two years. At the present level of definition of subsidence rates due to decomposition, constant slopes (straight lines) have been used to connect the rates of subsidence at time zero, six months, one year, and two years in Figure II-47.

The cumulative subsidence or settlement due to decomposition over time can be estimated by integrating the subsidence rate in Figure II-47 over time, i.e.,

$$S_D = \hat{k} \int_0^{0.5} 2t\,dt + \hat{k} \int_{0.5}^{1.0} (1.9-1.8t)\,dt + \hat{k} \int_1^2 (0.2-0.1t)\,dt \quad \text{(II-5)}$$

which is integrated over the two-year period to:

$$S_D = 0.575\,\hat{k} \quad \text{(II-6)}$$

where S_D = settlement due to decomposition, percent

$\hat{k}$ = average annual subsidence rate observed after 180 days of decomposition, percent per year

By integration of Equation II-5 over time, it is possible to predict the percent of the maximum settlement of a lift due to decomposition at any point in the two-year period. Figure II-48 shows the relationship between cumulative subsidence and time which is obtained by this integration. Approximately 45 percent of the cumulative or total subsidence occurs after six months, 91 percent after one year, 97 percent after 18 months, and 100 percent after two years. For example, at a $\hat{k}$ rate of 72 percent per year (as observed for a low-paper 65 percent saturated cell) the cumulative settlement after six months will be (0.45)(0.575)(72), or 18.6 percent of the height of the lift.

The relationships shown in Figures II-47 and II-48 provide a definitive means for estimating cumulative settlement over time due to decomposition and represent a direct initial step toward describing the behavior of settlement in landfills over time.

Initial Compaction

The degree of initial compaction of a test cell was predicted to be a function of the divergency of the unit weight of the sample from the equilibrium weight of the sample under the compaction stress of concern. In this study a base compaction stress of 1,260 lb/sq ft was used. Both the initial and final (equilibrium) unit weights of a refuse cell are functions of the individual type of refuse being considered and must be ascertained by appropriate testing. If these weights are known it is possible to predict the initial compaction using Equation II-3. In this study, typical initial compaction values of 20 percent were observed with dry refuse materials and 30 percent with partially-saturated or saturated materials.

Secondary Compaction

The secondary compaction phenomena observed in the study were found to be primarily pressure-dependent and, to a lesser extent, time-dependent. Within the scope of the study it was not possible to establish definitively the time dependency of secondary compaction. The degree of settlement due to secondary compaction in the laboratory studies could be described by a single relationship,

$$C_s = k_s \ln (p/p_o) \qquad \text{(II-4)}$$

Equation II-4 is the basic statement evolving from this study for describing the phenomenon of secondary compaction.

A Method of Prediction of Settlement

The settlement effected on a specific lift in a fill by each of the three mechanisms studied in the laboratory can be described by the expression,

$$S_L = 100 \left[1 - (1-0.01\ S_D)\ (1-0.01\ C_i)(1-0.01\ C_s) \right] \quad \text{(II-7)}$$

where:

S_L = settlement in a lift, percent

S_D = settlement due to decomposition, percent

C_i = initial compaction, percent

C_s = secondary compaction, percent

The determinations of S_D, C_i, and C_s have been discussed. It is important to note that, because of the assumption that each of these mechanisms is independent of the other, all of the above parameters (S_L, S_D, C_i, and C_s) are expressed in units of percent of original fill height.

Equation II-7 can be reformulated to summarize the settlement over a multiple-lift landfill by the expression:

$$S_{F_t} = \frac{\sum\limits_{t_i, p_i}^{n} S_{L_i}\ H_i}{\sum\limits^{n} H_i} \quad \text{(II-8)}$$

where

S_{F_t} = the settlement of the total fill due to decomposition, initial compaction, and secondary compaction at time t, percent of total fill height

S_{L_i} = settlement which has occurred in lift i over time t_i and pressure p_i, percent of lift height

t_i = age of lift in fill at time t

p_i = compaction stress on lift i at time t

H_i = initial emplacement height of lift i

Equation II-7 represents the summation of the effects of decomposition and compaction on landfill settlement as investigated in this study, and provides a basis for predicting landfill settlement using the laboratory-developed relationships of this study.

Example Calculation - Prediction of Landfill Settlement

The relationships reported in this chapter have been used to develop an example calculation predicting landfill settlement. The following conditions were assumed for the example:

(1) The fill was comprised of three 3-foot lifts of partially-saturated refuse, each lift being emplaced at 180-day intervals and compacted initially at 1,260 lb/sq ft;

(2) The average subsidence rate $\hat{k}$ was taken as 72 percent per year;

(3) The average weight loss in each lift was assumed to be 25 percent over the initial six months after emplacement and nil thereafter;

(4) The elevation at the base of the fill was assumed to be 500.00 ft;

(5) The in-place fill density was assumed for ease of calculation to be a constant maximum of 100 lb/cu ft;

(6) Each lift was assumed to be covered with a non-compactible overburden equivalent to 300 lb/sq ft; and

(7) Three years after start of the first lift, an overburden of 2,000 lb/sq ft was added above the three fill lifts.

The resulting data for the time-phased prediction of subsidence of the above landfill and landfilling conditions are summarized in Table II-29. The elevation of the topmost layer of the fill is predicted to decrease to an elevation of 509.38 after three years. The total in-place height of the three lifts plus two intermediate layers of cover material added in this time period is 15 feet, 40 percent of which (the cover material) was postulated to be non-compactible. The total settlement of the refuse material (exclusive of the two 3-ft layers of cover material between the three lifts) over the three-year period equalled 5.62 ft of the original 9-ft height of the three lifts, or 62.5 percent. In reference to Equation II-6, $0.57\hat{k}$ or 41.4 percent of the settlement relative to the original 9-ft fill height can be attributed to decomposition. That is, settlement due to decomposition accounted for two-thirds of the total settlement. The remaining one-third of the total settlement was attributable to initial and secondary compaction processes.

CHAPTER III

GAS MOVEMENT AND CONTROL

GENERAL

The fact that sanitary landfilling is the simplest, most economical procedure for the disposal of increasing quantities of wastes often contributes to a too frequently mistaken philosophy: "out-of-sight out-of mind." It is often forgotten that the nature of the disposed material can create environmental problems whether buried or not, and that the apparent simplicity of the sanitary landfill method of disposal does not obviate the need for competent planning, investigation, and control of the operation in order to avoid such potential problems.

Inside sanitary landfills, biological decomposition of organic matter occurs resulting in the production of gases. These gases primarily methane and carbon dioxide, may create problems which can restrict beneficial use of completed landfills by contributing to potential fire hazards and causing impairment of groundwater quality.

BASIC OBJECTIVES

Because of the importance of knowledge about gas generation, movement, and control for formulating construction criteria for sanitary landfills and optimum land development and use, basic objectives of the study included:

(1) The analysis and evaluation of the directions and extent of gas movement;

(2) The correlation between the direction and extent of gas movement and the surrounding soil characteristics;

(3) The performance of laboratory experiments for testing the effectiveness of various natural soils in reducing movement of gases from sanitary landfills; and

(4) The development of practical methods for controlling the movement of gases.

During the three years of the study, a major portion of the work effort was directed toward the accomplishment of these basic objectives.

Gas Movement

During the first year of the study, ten completed sanitary landfill sites were selected for conducting detailed gas movement studies. At nine of the sites, a soil sampling program was executed to obtain a knowledge of the nature of the soil material adjacent to the fills for use in interpreting the pattern of gas movement. Samples of soil were analyzed for determination of grain size distribution, soil classification, specific gravity, dry density, and moisture content. Field investigations were made to measure in-place density of the soils around the refuse sites and to visually survey the soil patterns in the immediate vicinity of the fills. A brief description of each research site is presented as follows (Reference 2):

Site 1

Site 1 was constructed in a worked out sand and gravel pit. Fill material consists of ordinary residential and commercial refuse and inert solid materials. Surrounding soils consist of gravelly sand with cobbles and small boulders. No reuse of the fill has been made. The adjacent land use is generally industrial in nature.

Site 2

Site 2 is located in a steep ravine in relatively isolated inland hills composed of medium-to-coarse-grained sandstone and conglomerate with lesser amounts of interbedded shales. The sandstone is generally well cemented with low porosity and low permeability. Both liquid and solid wastes were deposited at the site with minimal limitation as to their nature or source. No development on or adjacent to the site has occurred.

Site 3

Site 3 is located in a low lying, poorly drained, slough area, previously unsuitable for development. Surrounding soils are classified as silty clay underlain by silty sands and sandy silts. Solid wastes deposited in this site consists of ordinary household and commercial refuse and/or rubbish and garbage, and nondecomposable inert wastes.

Development in the vicinity of the site includes residential and industrial land uses. Development on the site includes an athletic field, parking areas, and commercial buildings.

Site 4

Site 4 was constructed in a small canyon in the inland foothills. The soils in the canyon generally consist of interbedded sandstone, shale, and siltstone. Wastes deposited at the site consist of residential and commercial refuse, industrial wastes, and tree stumps and limbs from clearing operations in the area.

Developments adjacent to the site consist of a mobile home park and a mobile home manufacturing firm. Improvements on the site proper are access roads and paved parking areas.

Site 5

Site 5 is located in coastal hills and was formerly mined for diatomaceous earth. Surrounding soils consist of silty clay, diatomite, diatomaceous mudstone, and shale. Fill material consisted of ordinary household and commercial refuse, rubbish, garbage, and other decomposable inert solids.

Surrounding development is primarily residential. The site surface is being developed as a botanical garden.

Site 6

Site 6 is one of several in a low-lying, poorly-drained, slough area, underlain by a thin layer of alluvial deposits consisting essentially of clay, silt, and fine sand. The landfill was a cut and cover operation and the walls of the excavation consisted of silty clay, sandy silts, and silty sands. Fill material consists of ordinary household and commercial refuse and/or rubbish, garbage, some liquid wastes, and other decomposable organic refuse and nondecomposable inert solids.

Development adjacent to the site is industrial in nature. No use of the site surface has as yet been made.

Site 7

Site 7 is located in a large canyon in hills situated in the central part of the Los Angeles area. The fill is being constructed as a park reclamation project and is entirely surrounded by park grounds. Final use of the site will be for recreational purposes.

Soils in the canyon are composed mostly of sandstone, decomposed granite, and gravelly and silty sands. Fill material consists of normal residential and commercial wastes and solid inert wastes.

Site 8

Site 8 was constructed in a worked out sand and gravel pit, adjacent to a groundwater recharge basin operated by a public agency. An inert, permeable fill levee was constructed to separate the spreading basin from the fill area. The pit had an average depth of approximately 50 feet. The exact nature of the material deposited in the site is not known, but apparently consisted primarily of organic decomposable material from many sources, and some solid inert wastes. Adjacent soils consist of gravelly sand with some silt, cobbles, and boulders.

A residential development is located adjacent to one side of the site. A mobile home park was constructed on a portion of the fill area. Because of differential settlement and subsidence of the surface, the mobile home park was abandoned, demolished, and cleared away. Salvage yards and a truck maintenance yard are now located on the site.

Site 9

Site 9 is also located in an abandoned gravel pit, with gravel and sand mining operations still in progress in areas adjacent to the site. Fill material consisted of ordinary household and commercial wastes and/or rubbish and garbage, and nondecomposable inert solids.

A residential development is located adjacent to one side of the site, with gravel mining operations on the other sides. The surface of the fill is planned to be a park. Soils in the area consist generally of silty sand and gravel.

Site 10

Site 10 is located in the San Francisco Bay area, and is one of many in that area which is reclaiming tidal lands. Site 10 was constructed by erecting impermeable solid fill levees around low-lying tidal lands and subsequent pumping of water from the area enclosed by the levees. Filling operations utilized a cell type fill and cover method for disposing of residential, commercial, and industrial solid wastes.

Monitoring Program

Gas may move in soils (porous media) by means of molecular diffusion or by convective flow (pressure gradient). The driving force causing movement of gas from one location to another by means of molecular diffusion is the concentration gradient of the gas between the two locations. At sites that are surrounded by dry permeable soils, where little concentration gradient exists at the refuse-soil interface, gases will slowly move out of the fill by molecular diffusion. A soil that is saturated with water produces an effective gas barrier; and if a fill is thus completed with a moist soil layer over the surface, or an impervious surface of any nature, such a barrier over the fill could cause gradient in the fill, and gas may move into surrounding soils (Reference 3).

To study this gas movement phenomena a monitoring program, comprised of installation of gas probes followed by gas sampling, was undertaken at the selected sites to measure gas concentrations in the soil atmosphere at various locations around the landfills. The gas sampling probes were made of 1/8-inch inside diameter (ID) plastic tubing with 1/16-inch wall thickness. The bottom 6-1/2-inch section of each probe was perforated, covered with a perforated plastic tube of 3/8-inch ID, and covered with a piece of burlap cloth to prevent clogging of the perforations.

The majority of the probes were installed at depths varying from two to three feet from ground surface; some were placed deeper because of soil conditions; and some were installed in the soil surrounding sewer manholes to get samples at deeper depths for comparison with samples taken at shallow depths.

Over the three-year period of the study, some of the probes were destroyed or lost, necessitating replacement or the installation of additional probes at new locations to facilitate the particular analysis being made at the time.

Sampling Procedure

The gas sampling procedure was based on the principle of displacing air in a sampling bottle by gases existing in the soil at the level of the probe. Two methods proved satisfactory: (1) liquid displacement, and (2) vacuum displacement. The vacuum method proved most efficient and was used for the majority of the gas samples taken. The liquid method is slower and has insufficient suction to draw a good sample through a partially blocked probe.

The procedure was to first evacuate the sampling bottles using a vacuum pump. Stop-cocks on the bottles were then made air tight to preserve the vacuum during travel from the laboratory to probe locations in the field. To sample each probe, the gas and air contained in the probe and its lead were first evacuated by the use of a hand aspirator to insure that a representative sample of refuse gas would be obtained. The probe was then connected to the sample bottle and the gas allowed to fill the vacuum in the bottle.

Gas Analyses

Analysis of the gas collected from each probe was performed using a gas chromatograph. Samples were analyzed in percent by volume for carbon dioxide (CO_2), oxygen (O_2), nitrogen (N_2), methane (CH_4), and in some cases, hydrogen sulfide (H_2S). The extent of the gas movement, primarily CH_4, from each landfill was pictorially demonstrated where possible by plotting contours of equal concentrations.

Methane gas is readily detected by an instrument which, when properly calibrated, will register the percent by volume of the combustible gas. Because of the many analyses desired for methane detection, particularly in conjunction with the monitoring of the testing of control devices, a Johnson-Williams Sniffer, Combustible Gas Indicator, Model G, fitted with a range multiplier unit was utilized. This unit is capable of measuring approximate methane concentration from 0 to 100 percent by volume. It proved to be reliable in the lower ranges and expedient for collecting large numbers of samples quickly. In addition, a Bacharach Instrument Company Gastron Gas Detector, Model 282, was purchased for use in measuring the concentration of methane gas. This particular detector, used extensively by natural gas companies for use in detecting gas leaks, is a sensitive instrument capable of detecting minute quantities of natural gas. The Gastron proved to be very useful in determining the presence of methane in buildings adjacent to landfills but is not built for use in measuring concentrations above approximately 20 percent by volume.

RESULTS OF GAS SAMPLING AND ANALYSES PROGRAM

Over the three-year period of the study, numerous gas samples were collected and analyzed at each site. The first-year program involved primarily a determination of the extent, if any, of gas movement away from the research sites. The results indicated which sites warranted additional study and where gas control systems could be installed and tested. The second-year program involved continuing analysis, at selected sites, to determine possible changes in gas concentrations and movement caused by rain, temperature, wind, and humidity. The third-year monitoring program continued the analyses for the purpose of determining change in concentration due to time lapse and any other determinable factors. Tables showing a summary of the gas analyses made during the study are included as Appendix E.

Site 1

Throughout the study period, the sampling and analyzing of gases in the surrounding soils were the most extensive at Site 1, particularly in conjunction with the testing of the control system. Plots of methane concentration contours consistently indicated continued production of methane within the fill. Gas movement was generally constant during the course of the study. The cover material over the fill is quite thick and of a material which allows little upward diffusion of gases; therefore, the gases move laterally into adjacent areas. A plot of methane concentration contours, derived from the results of the analyses of samples taken on 28 May 1969, is presented in Figure III-1. The benefits of control device testing are evidenced by the reduced concentration levels in the Gas Company parking lot across the street from the fill.

Site 2

Nineteen probes were placed in the earth fill across the axis of the canyon at Site 2. The probes were all placed in one horizontal plane at various distances from the refuse face. A review of the summary of the gas analysis data for this site in Appendix E indicates, for many of the probes, an early "bloom" of CO_2 with a following gradual decrease, accompanied with a later indication of CH_4; however, there was no consistency in the gas concentrations and movement of the gases through the earth fill. Water, often present in the probes, may be attributed to the watering of slope-protection plants on the earth fill.

Many of the probes at Site 2 were quite long and it was difficult to obtain samples from the probes because of plugging. Some inconsistence in the readings may also be due to the inability of obtaining a representative sample each time. No conclusive evaluation of the movement of gases at this site can be made with the data obtained.

Site 3

Sampling and analysis of gases at Site 3 were performed only during the first year of the project. Development activity and limited gas production indicated that continued investigation was not warranted.

Site 4

Gas movement studies at Site 4 were conducted for a period of one year and provided little information that could be utilized for comprehensive evaluation. The site has subsided causing many cracks and fissures in the surface of the fill from which gases vent to the atmosphere. Many gas probes on and adjacent to the site were destroyed by subsequent filling and construction.

Site 5

Site 5 was found to be producing gases; however, analyses of the samples taken adjacent to the filled area were inconclusive, indicating no significant migration of methane or carbon dioxide. Sampling and analysis of gases from probes installed in and on both sides of a barrier gravel trench, constructed prior to this study, showed that the trench is venting gases and inhibiting movement of gases across the plane of the trench.

Site 6

Analysis of samples collected from the probes at Site 6 over the study period indicated an irregular pattern of subsurface gas movement. Methane concentrations have been increasing indicating that the landfill is producing large quantities of methane. High methane concentration levels are isolated, however, and readings were sporadic, preventing the establishment of a definite pattern of movement. Natural soil formations at the site are stratified and heterogeneous, with alternating layers and pockets of coarse grained material and fine grained material, thus probably accounting for the irregular movement pattern.

During the last year of the study, movement of gases to the north of the fill was indicated when methane, surfacing through a crack in the floor of an industrial building, was accidently ignited. Probe sampling indicated spotted areas of high concentration levels, but no extensive movement. Figure III-2 indicates the locations of the probes closest to the site. Other probes located farther from the site, which showed no methane when sampled, are not shown. The percent of methane by volume for samples taken from these probes on 27 August 1969 is presented in Table III-1.

The north bank of this cut and cover landfill is stratified, much like the east edge, with deep layers of sand and/or sandy silt overlaid and underlaid with fine grained clays and silty clay material. These coarse grained layers are acting as "chimneys" for the transfer of the gases from the fill into adjoining soils where it escapes to the surface, under or around the building areas.

Site 7

No particular pattern of lateral gas movement was established during the probe sampling and analyses at Site 7.

Site 8

Sampling and analysis of gases from the probes at Site 8 were taken numerous times. Plots of the methane concentration contours for various periods, although similar in pattern, indicate a slight decrease in the extent of lateral gas movement into the adjacent area. A plot for the analyses of 17 September 1969 is presented in Figure III-3.

Site 9

Gas analyses of samples from the probes at Site 9 continue to show extensive movement of gases and high methane concentrations. There is no indication that a natural draft system constructed by the local governmental agency is reducing movement into an adjacent residential area. All of the sampling probes installed on the west and east sides of the site were destroyed by gravel extraction operations. Mining of gravel on these two sides of the landfill has now exposed three sides of the landfill and gases from the fill should begin to pass into the atmosphere causing a reduction of gas movement to the south. Analyses made of samples taken on 29 October 1969, however, do not reflect any decrease.

Site 10

Only two sets of samples were taken at Site 10 during the study. Continued work at the site precluded further monitoring of gases at the fill. Traces of hydrogen sulfide were found in many of the samples, indicating the intrusion of salt water into the fill from an adjacent ocean bay.

Gas Permeability Experiments

During the course of the study extensive laboratory experiments were conducted on a limited range of soils to determine the gas permeability characteristics of the soils under a range of no moisture content and gas pressure conditions, with the objective of studying the suitability of various soils as gas barrier membranes by determining methane diffusion-dispersion coefficients for such soils. Calculations for the coefficients were based on an analytical solution of the fundamental differential equation governing the flow of gases through porous media, and utilizing methane concentration history curves derived from each experimental test. Theoretical discussion of gas flow through porous media, derivation of the basic equation utilized to calculate the diffusion-dispersion coefficient, details of the design of the laboratory experiment, and the experimental procedure are presented in Reference 2.

Basically, the experimental test unit consisted of a plexiglass column, with a four-inch inside diameter and a three-foot length. At one end of the column were inlets for injection of a carrier gas (nitrogen) and a tracer gas (methane), a flow meter, and a manometer. At the other end, outlet pipes were provided for connection to a gas chromatograph and for exhausting gases. A drawing of the test column is presented in Figure III-4.

For each test the soil (porous medium) was compacted in the column in 4-inch lifts using a 5-pound hammer with a 12-inch drop. After compaction, the column was flushed with nitrogen to displace all air in the column. A known volume of methane, 0.5 to 1 percent of the void space in the column, was then injected at the rate of 1 milliliter per minute. Immediately after methane injection, the flow of nitrogen was restored at a predetermined rate and maintained at that rate during the remainder of the test period. Samples were obtained from the outlet end of the column and were analyzed to construct the concentration history curve which formed the basis for determining the diffusion-dispersion coefficient correlative to the soil. History curves present the methane concentration at the low pressure end of the porous media as a function of time elapsed following release of the pulse discharge (injection of methane).

Coefficients of diffusion-dispersion of methane through the porous media (soil being tested) were calculated using the following formula:

$$D = \left[\frac{L\int_0^\infty c\,dt}{2\sqrt{\pi}\;c_m t_m^{3/2}}\right]^2 \qquad \text{(III-1)}$$

Where D = Coefficient of diffusion-dispersion in ft^2/sec
L = Length of the column in feet
c = Methane concentration in percent
t = Time in seconds
c_m = Methane concentration at mean flow through time
t_m = Mean flow through time

The term $\int_0^\infty c\,dt$ is obtained by integrating the concentration history curve. For the purpose of these experiments, the point on the history curve corresponding to mean residence time was used for all calculations of the coefficient. Other necessary data measured or calculated for each test for each soil type were moisture content, porosity, density, inflow gas pressure, inflow rate, and degree of compaction. Mean flow through time, t_m, was evaluated by determing the centroid of the area under each concentration history curve; c_m was then determined for corresponding values of t_m.

Test Results

During 1967 four soils with different particle size distributions were independently tested at two levels of moisture content for each of three conditions of gas inflow pressure. Calculated values of diffusion-dispersion coefficients of methane for these tests are presented in Table III-2.

During 1968 a test was made of gas flow through a local soil sample where construction of a sanitary landfill had been proposed. Due to the long period of time required for tests under small inflow gas pressure conditions, no tests were conducted on this soil at inflow pressures less than four inches of water, as had been done on the other soils. Values of coefficients which were calculated for this soil are given in Table III-3.

Analysis of Results

The results of these experiments clearly indicate that the rate of movement of methane by diffusion-dispersion is slower through soils with fine particles than those with coarser particles, for both air-dry and optimum moisture conditions and under all conditions of inflow gas pressure. The diffusion-dispersion coefficients determined by these experiments represent the combined effect of molecular diffusion and convective dispersion. Because of the limitation on available instrumentation, it was not possible to conduct static molecular diffusion tests in this experiment, so it is not possible to distinguish between the molecular and dispersive components of the calculated coefficients. However, the high convective movement of gases in coarse grained soils is undoubtedly responsible for the high diffusion-dispersion coefficients of methane in these soils.

Gas also passes through the medium by convective flow when a pressure gradient is present. For determining the relative gas flow rate for a medium and its suitability as a gas barrier, this convective flow component should be considered. This flow component may be significant for the case of highly permeable media such as sand and gravel, whereas it will be rather insignificant for fine soils and when subject to small pressure gradients. No attempt was made to measure the gas permeability (coefficient of permeability) of the various media used in the experiment; however, when a fine soil is compacted under optimum moisture conditions to 90 percent or more of the maximum density, the gas permeability of the medium will be so small that the flow by pressure gradient will be reduced to inappreciable amounts. Total combined flow of methane, due to dispersion-diffusion and pressure gradient across a hypothetical membrane was calculated as part of the experiment and the results substantiate the presumption that fine textured soils, such as sandy clay, silty clay, or clay, form an effective barrier to gas movement even at low moisture content. When compacted at optimum moisture content, as discussed, these soils prevent any appreciable flow of methane or other gases under differential pressures of one or more atmospheres.

GAS CONTROL SYSTEMS

It has been demonstrated in many studies and extensively explored during the course of this study that gases generated by decomposition of refuse in a sanitary landfill can, under certain conditions and in particular soil types, move significant lateral distances from the landfill into adjacent soils. This phenomenon can be a matter of great concern, where methane gas is involved, if adequate measures are not taken to dissipate the gas and prevent such subsurface movement. Fires and explosions have resulted from accumulation of methane gas in confined spaces of structures on or adjacent to landfills after the gas became trapped and concentrations reached inflammable levels.

Measures which have been taken to prevent the movement of gases into adjacent soils (discussed in detail in Reference 2) include physical barrier and ventilation devices. The barrier device involves the placement of some membrane or other substance between the refuse in the landfill and the adjacent soils. A barrier may consist of a bitumastic material, such as asphalt impregnated jute; polyvinylchloride sheets or other plastic materials; gunite; bulkheading or sheet piling (although not a continuous barrier, may provide a barrier effect); or fine grained compacted and/or saturated soils. The ventilation device for controlling gas movement involves the release and venting of gases from beneath a building. When gases can escape through vent pipes or surface gravel-trenches, situated on or around the landfill, the gradient normally responsible for the movement can be lessened, thereby decreasing migration. Venting devices will often need to be constructed in conjunction with a barrier device to relieve the buildup of gas pressures within a fill. Examples of simple ventilation devices are: (1) "Tiki" burner pipes installed near the periphery of or directly on the landfill allowing the gases to be collected through the pipe and burned at the outlet on top of the pipe; (2) a more complex arrangement of perforated pipes, buried in a shallow gravel-filled trench on or around the landfill for collection of gases and venting at some central location; (3) vertical perforated pipes placed at the interface of the filled area and connected to a header pipe for conveyance to a central burner pipe or vent pipe; (4) a gravel trench around the landfill formed during filling operations for the full depth of the fill and left exposed at the surface for venting; (5) a series of gravel filled wells in which perforated pipes are placed for gas collection and conveyance; and (6) a layer of gravel with vent pipes under a building. A ventilation system may be composed of variations and combinations of the foregoing.

Project Control Systems

During this study, gas control devices were designed and constructed for three existing completed sites. These were sites where the gas movement monitoring program indicated an extensive migration of methane gas was occurring either into adjacent soils or through the fill cover.

Control System at Site 1

Site 1 is a completed landfill constructed in an abandoned gravel pit. The natural soil at the site consists of sand and gravel, with high methane diffusion-dispersion coefficients. Gas movement studies at the site confirmed extensive migration of methane into adjacent areas.

The device chosen for this site consisted of five wells, each 30 inches in diameter and 60-feet deep, spaced at approximately 40-foot intervals. Each well was divided into three horizontal sections, with each section filled with No. 2 gravel and topped with a one-foot layer of concrete. Three six-inch diameter pipes (one for each section) were installed in each well. The bottom portion of each pipe was perforated along its appropriate length for collecting the gases separately from each section of the well. The vent pipes were connected to an 18-inch diameter header pipe, by a six-inch diameter flexible, reinforced, neoprene hose; which was in turn connected to the suction side of a 25 HP blower. This blower was used primarily because it was owned by the public agency. Gases entering each vent pipe may be vented directly to the atmosphere or pumped by connection to the manifold system (Reference 2). A plan view and details of this system are shown in Figures III-5 through III-7.

Control System at Site 5

Site 5 is a completed landfill constructed in a large depression created by diatomite mining operations. Most of the soil at this site is composed of a silty clay with varying contents of diatomite. This soil is fine-grained, and generally effective in providing a natural barrier to the movement of gases laterally into adjacent areas. This was confirmed by the general lack of CO_2 and CH_4 in the soil atmosphere at the probes installed in the interior area of the fill. However, upward movement of gases through the fill cover was detected, and analyses indicated the presence of methane in the atmosphere within a greenhouse partially constructed on the landfill.

The site is being developed as a botanic garden and another greenhouse was planned for construction. Arrangements were made to install an asphalt-type membrane beneath the floor of the new structure to test the effectiveness of such a barrier in preventing gases from moving through the fill cover into the confines of the structure. The membrane consisted of a multiple layer, fiber reinforced, asphalt laminate fabricated in place.

The area within the foundation of the greenhouse, approximately 12 feet wide by 25 feet long, was excavated to a depth of 13 inches. A four-inch layer of gravel was placed at the bottom of the excavated area. Two three-inch diameter perforated pipes were placed in the gravel, one at each end of the area, to provide for venting of the gravel layer and to prevent excessive buildup of gas concentration under the membrane. A layer of sand was placed on top of the gravel to provide a base for the liner. The asphalt lining was constructed in place and extended over the structure footing to seal around the perimeter of the structure.

A layer of pea-gravel was placed on top of the liner to form the floor of the greenhouse (Reference 2).

To test the effectiveness of the liner as a barrier to the upward movement of gases, sampling probes were placed as follows:

(1) Three probes were placed at a depth of 3.5 feet under the floor of the greenhouse.

(2) Five probes were placed on top of the six-inch layer beneath the liner.

(3) Five probes were placed on top of the asphalt liner in the pea-gravel layer.

(4) Four probes were installed at various depths outside the foundation area and around the perimeter of the structure.

Figure III-8 is a plan view of this installation and indicates the probe locations (Reference 4).

Control System at Site 8

This site is a completed landfill of varying depth constructed in a depression resulting from gravel mining operations. During the gas movement monitoring program, high concentrations of methane were found in the surrounding soils a great distance from the boundary of the fill (Figures III-9 to III-11). Similar findings of such migration were reported during earlier studies at this site (Reference 3). The pattern of movement and the concentration levels showed little change from these earlier findings.

During the last year of the project, permission was granted for the installation of a gas control device on the site. The device consisted of a 750-foot trench, approximatety two-feet wide and six-feet deep, excavated along the westerly boundary of the fill and spanning the area where the greatest movement of gases was occurring. Two wells were located 200 feet apart in the center of the area where the methane concentration levels appeared to be the greatest. The device was constructed between the refuse fill and the property line in natural ground, adjacent to the interface. Provisions were made during construction for adequate surface drainage to prevent flooding of the system.

The two wells were drilled directly below the trench and also filled with gravel. Each well is 24 inches in diameter and 50-feet deep. One four-inch diameter perforated pipe was placed in each well, extending to the surface and capped, to provide venting for future experimental purposes. Each vertical well pipe is connected to a horizontal perforated pipe in the trench to provide a complete system of gas collector pipes. The vertical well pipes are also cross-connected to a nonperforated horizontal pipe to be used as a header pipe for future experimental pumping of gas from the wells. Shut-off valves are provided between the trench pipe and the well pipes. The trench was filled with gravel and capped with a layer of concrete to prevent any water from entering the trench. The vertical vent-burner pipe was provided with a metal hood to facilitate air flow around the opening. A cap, perforated with several 1/8-inch diameter orifices, was installed on the pipe to prevent the flash-back of any flame down the pipe. Details of the control system are shown in Figures III-12 through III-14.

Testing of Gas Control Devices

During the second and third year of study for this project, detailed testing and monitoring was conducted to examine the relative effectiveness of the control devices in reducing or stopping gas migration. Reference 4 reported in detail on the testing programs during the second year of the project for Sites 1 and 5. A summary of that work and the third year monitoring follows:

Site 1

The objective of experimentation at Site 1 was to identify the best operating procedure, in terms of sequence and duration of pumping from one or more of the five wells, to prevent the flow of gases produced in the landfill beyond the line of control wells. The probes installed at the site for the monitoring of gas movement were utilized for sampling, analysis, and evaluation of the testing results (Figure III-5). Typical gas concentrations found before testing began are shown in Figure III-1.

Second Year Testing - Site 1

Test 1: Test 1 consisted of connecting all pipes in Wells 1, 3, and 5 to the suction pump with Wells 2 and 4 open to the atmosphere. Duration of pumping was 28 hours. Gas analyses made prior to and after the pumping indicated that the system is capable of effectively preventing the flow of methane into the area immediately across from the line of wells and that complete removal of methane in the soil atmosphere could be achieved.

Test 2: Test 2 of the system consisted of pumping all the vent pipes of Well 3 for one hour each day while all the other wells were sealed. This schedule was maintained for three consecutive days with monitoring of the sample points each day. Pumping at this rate was continued for three more days, the pump was shut down, and a full set of readings was made at the sampling points. The rate of decrease in the concentration of methane was very small during this test, indicating that sustained pumping under such a schedule would not achieve the desired results.

Test 3: Test 3 consisted of the same well pumping arrangement as Test 2, but the duration of the pumping was increased to three hours a day. This schedule was maintained for four consecutive days. The results from this test were similar to Test 2, with gradual reduction of methane concentrations in the test area but at a faster rate than that realized in Test 2.

Third Year Testing - Site 1

During the first few months of the third year of the project, the public agency which operated the landfill and which had constructed the gas control system conducted a series of experiments, the results of which would be used as the basis for design of a similar installation at another landfill site with similar soil characteristics also experiencing gas migration problems. The basic objective of the experiments was to determine the maximum spacing for wells which would prevent gas movement and the minimum rate of pumping necessary for adequate control.

Test 1: Test 1 of the series began on 25 March 1969 and was continued for four consecutive days. The test consisted of merely venting (opening) all pipes in all wells to the atmosphere with no pumping. The sampling probes were checked once daily. Readings of concentration levels are shown in Table III-4 (Test 1). From the results of this test it can be concluded that simple venting of the wells produces no significant change in the methane concentrations and that the flow of gas into the adjacent area is not being impeded.

Test 2: Test 2 consisted of pumping from pipe "A" of the middle well (Well 3). The other two vent pipes in Well 3 and all other wells were sealed. Pipe 3A (Figure III-6) is the most shallow pipe in the well but has the most perforations and influences a zone from the surface of the ground to a depth of approximately 34 feet. The pumping schedule was set for five hours per day, and the system was tested for four consecutive days beginning on 1 April 1969.

Methane concentration readings were made before and after pumping each day. These readings are shown in Table III-5. Air flow measurements were made at the blower and at the vent pipe. Flow from the vent pipe measured 650 cfm (cubic feet per minute) and 1,900 cfm from the blower (the difference being due to leaks in the surface piping). Static pressure measurements and methane concentration readings were also made at all well pipes during all tests.

The results of Test 2 indicated that significant reduction in gas concentrations at the probes occurred after each pumping period, but that the concentrations returned to normal by the next morning and the zone of influence of complete methane evacuation in the area across from the fill was rather small (Figure III-15), indicating that the period of pumping should be increased for complete control. Negative static pressures were registered at all well pipes, indicating that pumping from just one pipe in the center well was creating an influence across the whole well plane.

Test 3: The third test involved the same pumping arrangement as Test 2, but the duration of pumping was increased from five hours a day to a continuous pumping rate (24 hours per day), at a flow rate of 650 cfm from the well pipe. The test began on 7 April 1969 and ran for four consecutive days. After the first day of operation the gas concentrations levels were significantly reduced, with many probes showing readings of zero methane. The next two days of pumping did not show any apparent increase in blower effectiveness, and the blower was shut off after the fourth day and all wells were capped. Continued monitoring of the probes showed a slow return of methane concentration levels, with a rapid return to pretest levels occurring at the wells. Table III-6 presents the methane concentration levels at the wells and probes during and subsequent to this test. Figure III-16 shows the area of influence where methane concentration was reduced to zero.

From the results of this test it can be readily concluded that continuous pumping (forced ventilation) from just one well of this system would provide a satisfactory gas migration barrier for the area under study. Static pressure readings indicate that the span of influence across the well plane is at least 170 feet, indicating that well spacings of 150 to 200 feet may be sufficient for satisfactory results.

Test 4: The fourth test by the public agency was made to determine the minimum flow rate from the vent pipe that would provide maximum barrier results. The speed of the blower could not be changed; therefore, in order to reduce the volume of gas being pumped from the well pipe, it was necessary to reduce the size of the pipe by placing a plate partially across the outlet end of the tee, between the tee and the flexhose connection to the header pipe. The point of flow measurement on the vent pipe was some distance down from this connection.

The flow rate obtained for this test was 118 cfm, with the same pumping arrangement as Test 2 being used. Testing began on 16 April 1969 and continued for three days. No significant reduction in gas concentrations at the probes was achieved at this reduced rate of pumping, and static pressure readings in most adjacent wells were positive, indicating that very little influence was being made in the well plane. Table III-7 presents the results of this test.

Test 5: The poor results of Test 4 indicated that a somewhat higher rate of flow than was developed during that test would be necessary to achieve the desired results. During Test 5 the rate of flow from the pipe was 315 cfm. Again, all pipes from all wells, except vent pipe 3A, were sealed. Pumping on pipe 3A at the above rate began on 21 April 1969 and continued for four days. Table III-8 presents the monitoring results for this test. The general conclusion that can be drawn from this test is that adequate stoppage of gas movement into the area across from the well plane can be achieved at this rate of flow from one pipe and one well, if pumped on a continuous basis. The area of influence (Figure III-17) was very similar to that achieved during Test 3 where the rate of flow from the well was 650 cfm.

Test 6: The previous tests, showing positive results, had all been conducted utilizing the mid-well of the control system. To better determine what spacing of wells would be satisfactory at other locations with similar soil characteristics, Test 6 was conducted using Well 1, the most southerly well. Again, only vent pipe "A" was connected to the blower, with all other well pipes capped. The primary purpose of the test was to determine if Well 5, 170 feet from Well 1, would be affected by pumping at Well 1, and also if the zone of influence in the adjacent area would be altered to any great extent. Figure III-18 indicates the area of influence for zero methane concentrations at the test probes as presented in Table III-9.

Test 6 began on 25 April 1969 and was conducted on a continuous basis at a pumping rate of 650 cfm for three days. Static pressure readings, also included in Table III-9, indicate that Well 5 vent pipes were affected by pumping from Well 1, confirming that the spacing of wells could be approximately 150 to 200 feet and still be effective for areas with similar soil characteristics as Site 1.

After the conclusion of Test 6, all well pipes were left open to vent to the atmosphere. Periodic monitoring of the probes were made for four weeks to check on the rate of buildup of gas concentration levels, and to determine if simple ventilation would serve to impede flow once the area has been evacuated of methane. Buildup of concentration levels was slow (Table III-9), but it may be concluded from the data that some forced ventilation across the plane of the wells is necessary in order to stop gas migration into the adjacent areas.

After the public agency had concluded its testing of the control system at Site 1, all vent pipes from the wells were again capped to allow concentration levels of methane in the area to build up so that testing could be continued, utilizing to some extent the knowledge gained from the prior testing. It had been demonstrated that pumping from the center well on a continuous basis (24 hours per day) would effectively control movement of gases across the plane of the wells into adjacent areas (Figure III-19). Knowledge as to minimum pumping time necessary for the same result was still needed. Therefore, tests with different pumping frequencies were scheduled. Discussion of these tests are presented below, continuing numerically from the tests conducted previously:

Test 7: Test 7 consisted of pumping from vent pipe 3A of the middle well with all other vent pipes capped. An automatic time clock on the blower was set for an on-off cycle of three hours on and three hours off, on a 24-hour basis, as follows:

ON	OFF
0530-0830	0830-1130
1130-1430	1430-1730
1730-2030	2030-2330
2330-0230	0230-0530

The blower was started at 1130 on 11 June 1969 and the above pumping cycle was maintained through 23 June. Periodic readings were made at the probes and wells during this period. Pumping rate from well pipe 3A was measured to be 650 cfm. Table III-10 presents the results of the monitoring program for this test.

Results of the monitoring indicate that this pumping schedule does impede the flow of gas across the plane of the wells and that concentrations remained fairly stable during the period of the test. Concentrations at the well plane, although not completely reduced to zero, are less than at pretest level, indicating that positive results can be achieved using an on-off pumping schedule.

Test 8: Test 8 made use of the same pumping arrangement as Test 7, but the sequence of pumping was changed to a cycle of 1-1/2 hours on and 4-1/2 hours off, on a 24-hour basis as follows:

ON (hrs)	OFF (hrs)
0700-0830	0830-1300
1300-1430	1430-1900
1900-2030	2030-0100
0100-0230	0230-0700

Again, the rate of flow from well pipe 3A was measured to be 650 cfm.

This test began at 1300 hours on 23 June 1969. The test continued on the set cycle through 28 July. Table III-11 presents the results of the monitoring program during this test.

During Test 8 methane concentrations at the wells uniformly increased at first but appeared to remain fairly stable for the remainder of the test. The level of concentrations at the sampling probes did not vary to any great degree from the levels that had been reached at the conclusion of Test 7, proving that the tested pumping cycle was capable of maintaining a barrier to any further movement across the plane of the wells. Readings at the deeper probes, those installed in manholes, were higher than those for the shallow probes in the same general vicinity, indicating that gas concentration at depth was not as effectively altered. However, the change in readings, even at depth, was minimal, demonstrating the ability of the control system to prevent the movement of gas into the adjacent area.

Test 9: During earlier tests, it was observed that the level of methane concentration at certain probes, even at shallow depth, remained fairly high and were not appreciably affected by the pumping schedule. This was true even of the tests conducted by the public agency; and, as mentioned above, the concentration of methane in the deeper probes continued on the high side.

Test 9 was initiated, therefore, in an attempt to completely evacuate the test area of methane, so that subsequent tests could be made to measure the effectiveness of the control system by monitoring the buildup of gas concentrations, rather than by reduction in concentrations. All pipes in all five wells were connected to the blower on 28 July 1969, after the conclusion of Test 5. Pumping was conducted on a continuous basis, 24 hours per day, continuing through 5 August, a period of eight days.

Readings of methane levels at the probes were made twice during the period and indicated that the gases in the area had been completely evacuated, even at depth. Readings at all previously high-reading probes were zero, except in the one manhole farthest from the well plane.

Test 10: On 5 August 1969, well pipes 1A and 5A, the two end wells of the system, were connected to the blower and a pumping cycle of 1-1/2 hours on and 4-1/2 hours off was set, identical with Test 8. The purpose of this test was to measure the effect of pumping from the two end wells in lieu of the middle well, check the zone of influence if possible, and check on the effectiveness of reading for increase in concentrations rather than decreases. The results of the sampling are presented in Table III-12. Pumping rates were measured to be 592 cfm from well pipe 1A and 674 cfm from pipe 5A.

The results of these tests indicate that the pumping arrangement and cycle was very effective in providing for the control of the movement of gases across the plane of the wells and the area of influence was extensive. The pump and blower system, selected primarily because of availability, were of excess capacity to accomplish the objective of interrupting gas migration to the Gas Company property.

Site 5

The testing program for the barrier membrane at Site 5 consisted solely of periodic sampling of the gases in the probes for monitoring the effects of the barrier on the concentration levels of methane below, above, and adjacent to the greenhouse. Monitoring was performed four times during 1969. Analyses of the samples were made using a gas chromatograph; Tables III-13 to III-16 present the results of these analyses.

In order to test the effectiveness of the ventilation device of the sand and gravel layer below the asphalt membrane, the vent pipes, installed at either end of the greenhouse, were sealed on 18 August 1969 so that the gases accumulated in this layer had no way of escaping. There was some question as to the validity of the results being obtained by the probes above the membrane because gas was not being allowed to accumulate directly below the membrane thus eliminating the possibility of gas penetrating the membrane. Also, there was some doubt as to whether or not gas was even reaching the gravel layer. Analyses subsequent to closing the vent pipes proved that the ventilating system did work and that gases would accumulate in the gravel layer but not penetrate the barrier to the probes above. Immediately upon reestablishment of the ventilation system, concentrations of gases in the layer again became zero. The results of all analyses indicated that the control system at Site 5 effectively prevents methane flow from entering the interior of the building being tested.

Tests were also conducted to determine whether a gravel-filled trench, installed by a public agency at Site 5 many years ago, was still effective as a barrier to the movement of gases from the fill into adjacent soils (Reference 2). Probes were installed at several locations along the trench (Figure III-20) both on the fill side of the trench and on the side opposite from the fill. Analyses of the gases (Appendix E) taken from these probes indicate that the trench is generally still acting as a good barrier.

Site 8

The construction of the control device at Site 8 was completed late in the third year of the project. During construction of the device 14 new probes were installed in the bottom of the gravel trench (six feet deep). One new probe was placed at the bottom of each of the two wells, and several probes were placed throughout the residential area adjacent to the fill, to replace those which had been destroyed during the course of the project. A plan view of this site showing the probe layout is presented in Figure III-12.

Construction of the control system was completed in November 1969. The gas emerging from the vent pipe for the system was ignited on that date, constituting the beginning of Test 1. Results of the gas analyses of the samples from the probes in the area are presented in Table III-17, covering a period of one month. Early evaluation of the results derived from the probe sampling would seem to indicate the ventilation utilizing only one vent pipe is insufficient to reduce the flow of gas into the adjacent area.

GAS TRAP EXPLOSION UNIT

Pacific Telephone Company has instituted a training course, and manual entitled "Training Course, Manhole Atmosphere Testing and Manhole Demonstration (Provisional)." A part of the course is a demonstration of the characteristics of toxic and flammable gases.

Every flammable gas has a lower explosive limit (LEL). This is the percentage by volume of that gas which must be present in air to constitute an explosive mixture. Percentages below this amount do not contain sufficient gas to propagate combustion. Every flammable gas also has an upper explosive limit (UEL). Gas mixtures of higher concentrations than the UEL will not explode due to insufficient oxygen. For some gases the range of explosibility is rather narrow while for others it is quite wide. There is a prevailing opinion that any commercial gas having in it one or more gases with a low LEL is quite likely to be more explosive than one which has gases with higher values of LEL (Reference 5).

Natural gas contains about 85 percent methane, 12 percent ethane, and three percent propane. The lower explosion limit of ethane is about three percent in air, and of methane about five percent in air. The upper explosion limits of methane and ethane are 15 and 12.5 percent respectively. A model manhole was built by the staff of the Training Division of Pacific Telephone Company, consisting of a model forced-ventilation blower, a control box, tanks of prepared gas simulating natural gas, a pressure regulator, and other appurtenances. The model manhole is made of plywood with a plexiglass front for observation, with a mounted cover attached by means of rubber bands which help absorb the force of explosions. An opening in the cover represents the entrance to the manhole and cover. This small cover is attached to the box by means of a string and rubber band. Six spark plugs are mounted in the back panel of the box and are fired individually or as a group by the use of a control box housing a rheostat switch for controlling the spark plugs. There is a spark coil in the control box which is powered by a six-volt battery.

After observing the operation of the model manhole unit it was decided to develop a similar unit to investigate the explosive characteristics of gases collected on the surface at selected research sites. The purpose was to measure the time it took to fill such a unit with flammable concentrations of gases and measure the concentrations prior to the time of ignition. It was also hoped to approximate the force delivered by known volumes and concentrations of landfill produced gases.

A "gas explosion unit" was designed and constructed consisting of two separate boxes. Carrying cases were made for each. The box in which the detonations occur is called an "explosion box" and it is controlled by an "explosion unit control" (Figure III-21). The explosion box simulates a confined space, such as a substructure or underfloor area of a building. It is made of plywood, held together with aluminum angles and has a plexiglass window, an opening in the bottom, and a small hole in the top. Six spark plugs are mounted in the back panel of the box near the bottom, the center, or the top of the box and may be fired in pairs or concurrently. Three outlets for sampling gas concentrations are mounted in the side of the box; one near the bottom, one near the middle, and one near the top. The explosion unit control box contains the source of power, a heavy duty 12-volt automobile battery, a 40,000-volt marine transformer coil, and a distributor driven by an automobile electric window motor. Switches mounted inside the control box provide for selection of the pair of spark plugs to be fired (Figure III-22).

The explosion box is placed in a shallow depression, one or two inches deep, framed by an opening in a 50 mil thick gas barrier membrane, six feet wide by six feet long. The control box is located about six feet from the explosion unit, connected by the cables between them. The surface of the ground under the control box on which the operators stand is covered by a rubber insulating mat, three feet wide by six feet long. Two operators perform the tests (Figure III-23).

The operators test the methane concentration near the bottom, the center, and the top of the box and record the readings. The chief operator selects the concentration at which he prefers to detonate, determines that observers are safely positioned, that the assistant operator is on the insulating mat, and authorizes actuation of the power switch (Figure III-24).

On Thursday, 24 July 1969, at Site 5, the gas explosion unit was field tested on landfill gas. Concentrations of less than 5 percent did not explode. Concentrations ranging between 5 and 10 percent were read immediately prior to explosions. These concentrations were reached within 10 minutes after previous explosions had resulted in complete evacuation of gases from the explosion box.

Subsequent experimentation at Site 5 with the gas explosion unit occurred on 1 October 1969, 8 October 1969, and 16 October 1969. On those days the operators were equipped with a form entitled "Gas Trap Demonstration Unit, Test Log, Installation Data." This log consists of two sheets. The test results of 8 October 1969 accompany those of 1 October 1969 in Tables III-18, III-19, and III-20. On 8 October 1969 the range of gases exploded successfully appear to be from 3.7 to 5 percent. On 16 October the range of cases exploded successfully appear to be from 3 to 5 percent.

The results of these tests indicate that: (1) the presence of gases other than methane, such as CO_2, may affect the explosion limits of the mixture being trapped; (2) the probes in the side of the box may not extend deeply enough into the box to obtain representative readings; or (3) the readings being obtained at this range of concentration are sufficiently inaccurate due to a lack of sensitivity of the instrument. However, it has been demonstrated that the use of this apparatus can effectively provide practical support for the theory of landfill gas flammability and potential enforcement of any future "Sanitary Landfill Ordinance."

CHAPTER IV

GROUNDWATER POLLUTION

CAUSES

Analyses of waters which have been in contact with solid wastes, such as refuse, have shown that both chemical and biological pollutants may be present. The liquids that result when water comes into contact with refuse either by percolation or immersion are generally termed leachates. The amount of leachate and its composition in a specific situation is dependent upon the material in the fill (organic or inorganic, soluble or insoluble), conditions in the fill (temperature, pH, moisture content), soil conditions (chemical chareacteristics, permeability), and volume and source of percolating water.

There are two primary ways portions of a fill may become saturated: (1) a fill can be in contact with groundwater or surface water, resulting in direct leaching through the fill material; and (2) capillary water may enter the fill. A considerable amount of water is required for the second condition.

In arid climates the normal incident rainfall is usually insufficient to saturate a fill. In climates with higher amounts of rainfall, saturation may occur. During the construction of a fill, saturation may occur due to evolution of poor drainage conditions. Unsatisfactory drainage and the successive application of large quantities of water to the surface, such as irrigating agricultural crops and watering of parks and golf courses, can cause leachate in and adjacent to completed fills.

Groundwater in the immediate vicinity of a disposal site may become polluted and unsuitable for domestic and/or irrigation use if the solid wastes intercept the zone of saturation and come into contact with the groundwater or if the leachate reaches the groundwater. Concentrations of common mineral constituents such as hardness and total dissolved solids in leachate contaminated groundwater may be many times greater than those normally found in groundwater. The profile of pollutants in the groundwater is controlled by the pattern of groundwater movements and chemical and biological interactions within the groundwater environments.

Pollutants leached from solid wastes will be transported in the same general direction as the direction of the groundwater flow excepting deviations due to macromolecular transport phenomena. Vertical transport or diffusion is due to minimum mixing conditions in the aquifer. Exceptions to this concept may occur as the result of vertical density gradients and in the vicinity of a well; as a consequence, the natural pattern of water movement may be changed by pumping (Reference 6).

Permeability of the soil is the property of transmitting water. Velocity of water through material is dependent upon the permeability. The retention within the material in the cell is a function of the velocity and therefore a function of the permeability. Ideally a sanitary landfill should be located above an impermeable horizontal formation with the top of any groundwater or phreatic surface a considerable distance below the base of the fill. The surface drainage should be directed away from the fill area. These conditions are ideal but rarely exist. Frequently, sanitary landfills are located in areas underlain by a permeable formation. Often the water table is close to the ground surface and surface conditions are such that much precipitation percolates to the groundwater. Often surface drainage and groundwater flow move in the same direction. The eastern foothills of the Los Angeles Basin, where a number of gravel pits have been used for waste disposal sites, are an excellent example of such conditions. These gravel deposits form the large alluvial fans found at the mouth of the streams draining the San Gabriel Mountains. These deposits consist largely of uncemented sands, gravels, and coarser materials forming good aquifers and are extensively drilled to furnish water supplies for various communities.

Indices of groundwater pollution were determined in laboratory experiments during this project. Leachates were analyzed for total dissolved solids, chemical oxygen demand, hardness, alkalinity, pH, organic and ammonia nitrogen, fluorides, sulfates, and nitrates. An analysis of these leachate production characteristics was conducted in the laboratory. These characteristics were studied at varying stages of decomposition of typical refuse materials. A leachate pollution index enabling predictions of the expected quantity of leachate from a given landfill area, under known conditions, was developed and is described herein (Reference 4).

The major gases normally produced within a sanitary landfill are carbon dioxide and methane. Since methane is relatively insoluble in water, it is not expected to contribute materially to groundwater pollution. Carbon dioxide gas is highly soluble in water and may contribute to increased mineralization in groundwater. Carbon dioxide may combine with water to form carbonic acid which in the presence of calcium or magnesium salts, present in many soils, releases calcium and magnesium ions. Other compounds such as sulfates, chlorides, and silicates may also leach from landfills into the groundwater.

Because of the multitude of questions which have been raised regarding the impairment of groundwater by carbon dioxide, all available data was collated in 1960 by Engineering-Science, Inc. (Reference 8). This report recommended that a number of specific research projects be conducted. One of the specific recommended projects was concerned with water pollution by carbon dioxide generated by refuse decomposition (Reference 6). During this project, a pilot scale landfill was constructed in an unused gravel pit with sufficient monitoring devices to study the generation and movement of refuse-produced gases into the surrounding soil and outside atmosphere. This project clearly demonstrated the concentrations of carbon dioxide which can be generated in a sanitary landfill. The results are summarized:

(1) Comparative rates of movement of refuse-produced gases into the surrounding soil and free atmosphere were established.

(2) From 15 to 20 times more CO_2 passed upward through the one-foot silt cover than passed into the soil, indicating the importance of the nature of the fill cover in allowing refuse gases to escape.

(3) Carbon dioxide was found in significant quantities in the adjacent soil.

(4) Sizable concentrations of carbon dioxide may be expected to be held at the bottom refuse-soil interface for many years, with CO_2 passing into the ground.

(5) Effects of carbon dioxide on a particular groundwater depend on several factors still being studied. Through analysis of

the gaseous atmosphere within and surrounding operating landfills, it is possible that predictions can be made regarding groundwater pickup.

Because of the amount of carbon dioxide generated within a sanitary landfill and because it is the only gas generated in quantity which is readily soluble in water, carbon dioxide should be considered as a groundwater pollutant. However, water that has been impaired by carbon dioxide will be diluted in varying degrees within the groundwater body.

LEACHATE EXPERIMENT

Boring samples from sanitary landfill Sites 1 and 12 were tested during the leachate experiment. These samples were obtained as part of the drilling program described in Appendix C, "Field Investigation by Converse, Davis & Associates." The material removed from the borings was placed in 55-gallon steel drums, weights were determined, and the samples were then thoroughly mixed. During the mixing operation, rocks larger than three-quarter inch diameter and metals were removed by hand. Moisture content of the refuse was determined by drying representative samples in an electric oven. After mixing and moisture content sampling, the bulk sample was quartered and loaded into a polyethylene bag contained inside a heavy-walled paper bag. The bags were sealed to prevent loss of moisture. Individual bulk samples were pulverized in a hammermill in which the material was graded to a maximum size of about one-quarter inch. Approximately one-half cubic foot of each sample was retained, sealed in a sturdy polyethylene bag, and shipped to the Engineering-Science, Inc. Laboratory at Oakland, California.

Two synthetic samples were prepared based on guidelines established by the American Public Works Association (Reference 3). These refuse samples are referred to as typical refuse (TR) and refuse high in garbage (RH). These samples were leached simultaneously under the same procedure as the field samples to provide a comparison. Moisture and volatile content were determined and each ingredient of the synthetic refuse was analyzed separately. The composition of the synthetic refuse is indicated in Table IV-1. Moisture and volatile matter content, determined as loss on ignition, are presented in Table IV-2. Three different leaching systems were applied concurrently with time to each tested sample. These are referred to as Series 1, 2, and 3 (Figure IV-1). Moisture and volatile matter content in the test samples are shown in Table IV-3.

Series 1

A six-liter container was filled with uncompacted refuse samples which were weighed and transferred to leaching jars. The sample in each jar was completely immersed in water and an additional 1,500 milliliters (mls) was added. During the experiment no water was added. After one, eight, and 40 days leachate samples of 250 mls were withdrawn and analyzed for chemical oxygen demand (COD), total dissolved solids (TDS), Kjeldahl ammonical and organic nitrogen (N), hardness (HRD), alkalinity (ALK), and pH (Reference 9).

Series 2

Distilled water was added to completely immerse the samples. After one, eight, and 40 days, 250 mls of leachate were withdrawn to provide continuous immersion.

Series 3

The refuse samples were saturated as in Series 1 and 2. After one, eight, 23, and 40 days they were drained completely and the drain volumes were replaced by equal volumes of distilled water.

Table IV-4 indicates the initial refuse weights and water volumes used in the three series. Because the refuse samples were loosely placed into the leaching jars, the weights (W) and the specific gravities (γ) represent the loosely placed conditions. W and γ are inversely proportional to the paper content of the samples. The smaller the specific gravity of the refuse the more volume of water was required for complete immersion. Table IV-5 indicates the calculated volumes of water required per unit weight of the test samples. During the last sampling period, leachates from Series 2 and 3 were analyzed for chlorines, sulfates, and nitrates (Table IV-16).

Test Results

The results of the experiment indicate several general trends. Tables IV-6, IV-7, and IV-8 contain the results of analyses of the leachates obtained from Series 1. There appears to be a definite correlation between the COD and TDS in the leachates. During the experiment, leachates of Site 1 samples exhibited a considerable increase in COD and TDS concentrations. This increase is attributed to the existence of organic matter and the seeding in of anaerobic organisms during the experiment. The drop in pH of the Site 1 samples is an indication of the first stage of anaerobic decomposition. In the Site 12 sample CC 2-3, the release of COD and TDS practically stopped after the eighth day. A relatively constant pH value of 6.5 was measured during the first eight days and 5.85 after 40 days. This sample exhibited the highest COD, TDS, and HRD together with the lowest pH at the beginning of the experiment, indicating the existence of large amounts of partially decomposed organic material that became readily decomposable under favorable moisture conditions.

The same correlation between COD and TDS was observed in the synthetic refuse. However, the COD of the leachate decreased toward the end of the experiment, probably because the sample contained less organic matter. Although hardness and alkalinity exhibited a general trend of increased concentrations, a correlation with other properties was not distinct.

Series 1 changes in the Kjeldahl nitrogen concentrations were not significant; however, the landfill samples were considered to be deficient in organic nitrogen. Series 2 experimental results supplement the observations made during Series 1 testing. Tables IV-9, IV-10, and IV-11 present the Series 2 data. Because the weights of refuse and volumes of leaching water are different, a comparison with the concentrations obtained for Series 1 is not possible. Although the correlation between COD and TDS is satisfactory, the TDS and COD for the CC 2-3 sample started to decrease. Hence, in Series 1 by obtaining a constant concentration and in Series 2 where a constant concentration was exhibited when fresh solvent was added, sample CC 2-3 appeared to be approaching stabilization. The general reduction in the Kjeldahl nitrogen of all the landfill samples correlates with the conclusion in Series 1 that they are deficient in organic nitrogen.

Series 3 testing more closely represents the typical extraction process of soluble materials by leaching. This process was simulated four times during the Series 3 tests. The data is presented in Tables IV-12 through IV-15. In all the samples only the Kjeldahl nitrogen was depleted steadily. Conversely, in the landfill samples alkalinity generally increased. In the synthetic refuse samples alkalinity remained practically unchanged. Although COD and TDS behaved similarly, variations in the behavior in different samples were observed. Only sample CC 2-3 was steadily depleted of COD, TDS, and HRD, further indicating that decomposition of this sample was attenuating.

In the other landfill samples a temporary reduction in soluble materials was noticed after each draining. This was due to the extraction of previously formed metabolic products. This was followed by a recovery in which COD, TDS, and HRD increased, thus demonstrating continuity of release of the solubles.

The synthetic refuse did not demonstrate the initial reductions expected of a partially decomposed refuse. At incipient decomposition, increased leachate concentrations were observed. Due to a reduction in the rate of decomposition toward the end of the experiment, a gradual decrease in leachate concentrations were observed.

The total amount of leachable materials present during the period of the experiment was calculated as follows:

For Series 1

$$L_T = V_o C_{t1} + (V_o - 0.250) \ (C_{t2} - C_{t1}) + (V_o - 0.500) \ (C_{t3} - C_{t2}) \qquad \text{(IV-1)}$$

For Series 2

$$L_T = V_o C_{t1} + \Big[V_o C_{t2} - (V_o - 0.250) C_{t1} \Big] + \Big[V_o C_{t3} - (V_o C_{t3} - 0.250) C_{t2} \Big] \qquad \text{(IV-2)}$$

and For Series 3

$$L_T = V_o C_{t1} + \Big[V_o C_{t2} - (V_o - V_1) C_{t1} \Big] + \Big[V_o C_{t3} - (V_o C_{t3} - (V_o - V_2) C_{t2} \Big] + V_o C_{t4} - (V_o - V_3) C_{t3} \qquad \text{(IV-3)}$$

where:

L_T = is the total amount (or load) of leached material, in gms, including all the material in solution in both the withdrawn samples and the remaining water in contact with the solids;

V_o = Volume of water initially added to the refuse sample, in liters;

C_{t1}, C_{t2} .. etc. = concentrations of leached material after times t1, t2, etc. in gms/liter. In Series 1 and 2 each time a volume of 250 ml was extracted for chemical analyses; and

V_1, V_2...etc. = are the water volumes drained in Series 3 at times t1, t2..etc., which were replaced by equivalent volumes of distilled water.

Equations (IV-1), (IV-2), and (IV-3) were developed on the basis of the ideal or the equilibrium stage concept in which the solution adhering to the solids has the same composition as that in the overflow (withdrawn) sample. Series 1 approaches this condition more than the other two series due to the presence of excess solvent. The amount of material released in solution may be expressed as ppm (or gms/ton) of the refuse sample as:

$$S_t = \frac{L_t}{W} \times 10^6 \qquad \text{(IV-4)}$$

L_t and W are in grams or similar weight units.

The application of Equation (IV-1) to Series 1 provides the variation of leachable solutes with time in the presence of excess solvent. In a given climatological environment this variation depends upon the composition of the sample and its stage or degree of decomposition and, thus, it is an important and unique characteristic. Sample calculations for this variation in Series 1 are presented in Table IV-17.

In addition to the general similarity between the patterns of increase of COD, TDS, and HRD, a reduced rate of increase of COD is noted more distinctly. During decomposition, TDS and HRD increase until a stable maximum value is reached. However, COD may be expected to increase and then decline as the released organic material stabilizes in the liquid phase. Figure IV-2 presents a suggested hypothetical variation of leached COD and TDS.

The ratio of COD/TDS increases during active decomposition. This ratio then declines slowly and approaches zero as decomposition tends to cease. Plots of this ratio from the experimental observations in Series 1, Table IV-18 and Figure IV-3 show that after 40 days of contact with the solvent water these three stages were found in the following samples:

(1) Sample (TR), the typical synthetic refuse with little garbage content has completed stage 2 and is well into stage 3;

(2) Sample (RH), the synthetic refuse high in garbage content, and sample CC 2-3, the landfill sample, exhibited characteristics of stages 1 and 2; and

(3) Samples BR 1-8, BR 2-4, and CC 1-2, landfill samples were still in stage 1 with similar variation patterns at the end of 40 days.

The amounts of materials released during Series 1 are presented in Table IV-19 as tons per acre foot based on a refuse density of 500 lbs/cu yd.

Less leachate was separated in Series 2 than in Series 1. Water adhering to the solids in Series 2 had higher concentrations than those of the withdrawn samples and there was less excess water in Series 2 than in Series 1. This demonstrates the direct relationship between the volume of excess water and of the quantity of removable material in the solvent medium, i.e. the rate of leaching is significantly dependent upon the rate of application of the solvent. Table IV-20 is a sample calculation sheet of Series 2 and Table IV-21 indicates the approximate leachable quantities of chlorides, sulfates, and nitrates in Series 1 and 2 samples after 40 days. The observed variation of the leached amounts of chlorides in the different samples is apparently independent of the pollution index of the refuse or the amounts of other leachates. Leachable sulfates and nitrates generally, but minutely, vary with the degree of decomposition.

Sample CC 2-3 had a high volatile matter content and exhibited the fastest rate of decomposition. Based on the release of leached nitrogen versus time it may be concluded that the reason for the accelerated decomposition of this sample is the existence of adequate nitrogen content and that the rate of decomposition is considerably affected by the availability of the necessary nutrients for bacterial activity, indicating that to achieve the optimum rate of decomposition, mixing of the various ingredients of refuse would be advisable.

It is proposed that the total dissolved solids (TDS) be chosen as the index for leaching from refuse landfills. Variations in quantities of leached TDS appear to be directly comparable to those of leached COD. During the leaching process, TDS reaches an upper limit and does not undergo further significant change. Until this upper limit is reached, decomposition continues to release more dissolved solids into the solvent medium. The process of refuse leaching may be described as two concurrent events:

(1) Removal of solutes by leaching; and

(2) Replenishment of solutes due to decomposition of refuse materials. Sample chemical analyses and other pertinent calculations made during Series 3 sampling verify this. Substantiating data is presented in Table IV-22.

The amount of solute in the initial "underflow" is obtained by multiplying TDS in parts per million from Table IV-23 by the weight of the refuse sample. The amount of solute in the "overflow" is the weight of the drained volume multiplied by the measured TDS concentration given in Tables IV-12, IV-13, and IV-14. The amount of solute remaining in the "underflow" at any point in time is calculated as the difference between these two values. The total amount of solvents in the overflow and underflow is equal to the amount originally added to immerse the sample. The variation of leachable TDS with time obtained from Series 1 is presented in Table IV-23.

The best possible method for predicting the chemical composition of leachates produced as a result of inundating a landfill is by leaching representative samples in the laboratory and applying the measured concentrations of solutes to a field scale without extrapolation. Table IV-24 indicates the expected TDS leachate load if an inundation program similar to the Series 3 experiment was applied to a landfill with an average unit weight of 500 pounds per cubic yard.

During the leachate experiment the following observations were made:

(1) The degree of compaction of refuse material affects the volume of water required to saturate and, therefore, the quantity of leached materials.

(2) The permeability of the refuse material affects the contact time between water and the refuse solids.

(3) The rate of decomposition is affected by climatic conditions, thereby affecting the quantity of leachable solutes.

(4) The tendency of solids to disintegrate will be less in the compacted refuse in actual landfill conditions.

CARBON DIOXIDE

Free carbon dioxide is undesirable in water supplies. It will increase the corrosiveness and aggressiveness of water (Reference 10). The process by which gases are dissolved in water is known as absorption and involves the transfer of gas into a liquid, in which it is more or less soluble (Reference 11). Nearly all gases are soluble in water to some degree. The rate at which the gaseous constituent of a mixture will dissolve in an absorbent liquid depends upon the extent of departure from equilibrium, the manner in which the liquid and gas are brought into contact with each other, and the degree of chemical reaction between the gas and liquid. Carbon dioxide has a high degree of solubility and is found in large quantities in landfills.

Dissolved carbon dioxide reacts with water to form carbonic acid,

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

which in turn dissociates to form bicarbonate ions,

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

If solid calcium carbonate is present within the soil, carbonic acid will react with it to form soluble calcium bicarbonate. The overall reaction would be:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{++} + 2HCO_3^-$$

When this reaction takes place in the presence of free carbon dioxide, the carbon dioxide removed from the water leaves room for more to dissolve and the process continues until an equilibrium is obtained. The resulting increase in calcium hardness is the principal undesirable effect associated with carbon dioxide in groundwater. The process will reverse itself when the groundwater flows to a region where the soil atmosphere is low in carbon dioxide.

The actual mechanism by which carbon dioxide is absorbed into water from a gas stream moving to the groundwater table is complex. One would expect, however, that water percolating through a refuse landfill which produces leachates would also contact large amounts of carbon dioxide within the fill and absorb it. The ability of the leachate to absorb carbon dioxide may be reduced by the presence of leached salts already in solution but the capacity reduction would diminish as salts were removed from the fill. Because of dilution and the potential number of sources of contaminants it is difficult to determine the origin of water impairment.

GROUNDWATER MONITORING

There have been very few complaints regarding the quality of the groundwater in the Los Angeles Basin area which can be related to possible pollution from a landfill. Several aspects of one such complaint were carefully investigated and fully documented. The results of these efforts are of interest because they indicate a particular problem which may be prevalent in existing landfills but which can be avoided by appropriate practice in the future.

Landfill Site 8 was located in an abandoned gravel pit situated in a broad alluvial cone extending from nearby mountains. It is 400 feet from a water well having a history of impaired water quality. The site had been thought to be responsible for the water quality impairment and had been the subject of a number of studies.

In 1955 the operator of the landfill was issued a permit on condition that the pit be filled with inert solid fill to an elevation of 5 feet above anticipated high groundwater. Active material was then permitted above this elevation. In 1958 taste and odor problems developed within the water system of the local water company. Investigation of complaints by the water company indicated intermittent musty taste and odor problems within the service area of the well. After discontinuing use of this well no further complaints were received.

The water company then contacted the Regional Water Quality Control Board and an investigation was undertaken to determine the source of the contamination. The localized nature of the groundwater impairment indicated a local source--the presence of both recent and historic dumps in the vicinity were potential causes. The Site 8 operation was the closest.

The Regional Water Quality Control Board then requested the California State Department of Water Resources to investigate this problem (Reference 12). It was found that the groundwaters of the water basin were generally of excellent mineral quality but there was a history of water quality impairment by carbon dioxide in some wells within the basin. Carbon dioxide was found in the alluvium above the impaired groundwaters. The investigation concluded that the impairment of the well water quality was primarily due to a solution of carbon dioxide gas and that the major source of carbon dioxide in the vicinity of the well was decomposing refuse in the Site 8 landfill. These findings and conclusions developed by the Department of Water Resources were based on the assumption that the filling operation at Site 8 had been carried out as prescribed in the permit requirements. These conclusions of the Department of Water Resources have been a significant factor in decisions to inhibit the installation of new filling operations in areas with similar geology.

Subsequent to the above activities a private engineering geologist made several test borings within the site. All of the borings, with one exception, showed large amounts of water within the rubbish. All of the test borings located decomposable rubbish below the allowable elevation. Conclusions based on this information indicated that the degradation of the well water quality was caused by one or more of the following:

(1) Surface water from adjoining areas was allowed to flow onto the rubbish fill and percolate through the fill to the underground water supply.

(2) Rubbish placed below the high groundwater elevation was saturated by an adjacent spreading ground and the resulting leachate was forced in the direction of the well.

(3) The high moisture content of the rubbish caused rapid decomposition resulting in excessive amounts of carbon dioxide which then mixed with the underground water.

CHAPTER V

CRITERIA FOR THE LOCATION, DESIGN, AND CONSTRUCTION OF SANITARY LANDFILLS

LOCATION

Ideally, planning for use of a completed sanitary landfill should result in the highest and best use of the land. The selection of a location for a sanitary landfill should be based on benefit to the community while assuring maximum personal safety and security of any adjacent property. A sanitary landfill site should conform to the general plan of the community. Those components of the general plan which are most affected by the selection of a location are the land use plan, the solid waste plan, the street and highway plan, and in many cases the recreational plan. The general plan may be importantly affected by a correlation between the recreational plan and the solid waste plan. Designating a site for recreational reuse could greatly improve public acceptance, thus lessening the problem of locating a landfill. The monetary values of a proposed landfill site, as well as neighboring properties, may increase if a proposed development is kept compatible with the community and presented in a manner to which property owners may react optimistically. Where planning includes the reclamation of otherwise unusable lands and provides for a land use higher than that existing prior to reclamation, landfilling should be encouraged.

The suitability of any potential location is a function of the local topography and geology. Existing depressions in lands, such as old gravel quarries, normally useless gullies, and under certain circumstances abandoned coal strip mines may be suitable for landfill sites. The prime physical considerations of a potential location are the practicality of preventing water pollution and gas migration. The location of the groundwater and the permeability of the native soils should be determining geological factors. If a proposed site is in permeable soils and a gas control system is not provided, permission to locate a landfill should be withheld. Sites subject to uncontrolled flooding such as river beds, stream beds, swales, flood plains, or washes should not be used. In many parts of the country, landfills are not permitted within a horizontal distance 50 to 100 feet of the official-right-of-way of any water course or proposed drainage channel.

To minimize water pollution from leachates and gases, sanitary landfills would be most ideally located above native soils of low permeability, if over a water supply. Among the most common materials with low permeability and those which are also most effective in filtering out biologic organisms are clay, shale, silt, and glacial till. Sites where sand and gravel, limestone, or dolomitic rock occur offer no such advantage because these materials have a high permeability and would require installing barriers to prevent water pollution.

Decomposable solid waste in sea water, salt water, or waters with high sulfate content often reacts to form hydrogen sulfide gas. Hydrogen sulfide gas is exceedingly toxic and dangerous. Therefore, sanitary landfills should not be permitted in sea water, salt water, or waters with high sulfate content.

General planning should provide for a reasonable separation distance between sanitary landfills and adjacent incompatible land uses. Consideration must be given to the observed distances that significant concentrations of explosive and toxic gases have migrated. A reasonable minimum separation distance between a sanitary landfill interface and adjacent closed habitable structures is recommended as 1,000 feet. In general, it would not be practical to allow variances to this requirement, because of uncertainties with respect to geological and engineering potentials at the time of planning. Chapter VII gives possible conditions for varying the separation distance from adjacent land uses after specific knowledge about individual landfill sites has been determined.

The Los Angeles Regional Water Quality Control Board of the State of California undertook a major study of groundwater storage basins and the effect upon them by the disposal of wastes onto land. As a result of this study, disposal sites were classified into three general classes.

A Location, Class I Site, is a site located on nonwater-bearing rocks or underlain by isolated bodies or normally unusable groundwater, which are protected from surface runoff and where surface drainage can be restricted to the site or discharged to a suitable wasteway, and where safe limits exist with respect to the potential radius of percolation.

Location, Class II, is a site underlain by normally usable, confined, or free groundwater when the minimum elevation of the landfill can be maintained above anticipated high groundwater elevations, which are protected from surface runoff and where surface drainage can be restricted to the site or discharged to a suitable wasteway.

Location, Class III, is a site so located as to afford little or no protection to normally usable underground waters.

DESIGN

Water Pollution Prevention

Gases or leachates from landfills may migrate or be carried by intruding waters into contact with underlying groundwaters resulting in pollution. This pollution may be prevented by keeping the potential pollutants from reaching the waters.

One means of separating water and pollutants is by requiring a vertical separation distance between the bottom of the landfill and the high water surface of underlying groundwaters. In soils of low permeability the required vertical separation distance varies from state to state. In California the requirement has been 10 feet. In Illinois 30 feet is required unless studies indicate a lesser depth is satisfactory (Reference 13).

In permeable soils, the results of extensive studies of groundwater contamination indicated that in pollution from sanitary waste, regression of quantities of E. Coli accompanied an increased solids accumulation. Ultimate bacteria travel during a wet season was rated as about 80 feet in a sandy soil (Reference 14). Although the densities of leachate may be different from sanitary waste there is reason to anticipate a corollary in the phenomena of straining and sedimentation resulting in clogging and ultimate barrier formation. Until results of testing under control conditions yield satisfactory distances, landfills located in permeable soils less than 30 feet above groundwater should be underlain with barriers to lessen the chance of pollution.

A drainage gallery may be required to keep underground waters from flowing across the interface between the landfill and natural soil, where several aquifers separated by impervious soil would be intersected by a proposed landfill. The drainage gallery could consist of closely spaced vertical drainage wells interconnected by tunnels at the bottom, with suitable outlets, and either horizontal drains or pipes placed in trenches. Interconnection between the vertical wells may be accomplished by horizontal drains. Vertical wells should be backfilled with permeable material and may be augmented by a perforated pipe installed vertically in the center of each vertical drainage well. All subsurface drainage design should consider the damming effect of heavy embankments and the possible raising of the groundwater table.

In addition to subsurface controls and setbacks--ditches, piping, and dikes should be used, where necessary, to keep surface waters from flowing across the interface of the landfill and natural soil. This will minimize erosion of the earth cover and water intrusion, thereby minimizing leachate production. All such diverted waters should be guided to properly operating drains.

The means for accomplishing the separation of water and pollutants requires planning for the construction of the landfill. Original construction plans should show the proposed means of controlling the basic types of water intrusion: (1) surface water percolating through the soil cover; (2) adjacent water moving horizontally through the side of the fill; (3) water entering from beneath the fill due to a rise in the groundwater level; and (4) water present in the site prior to or at the time of refuse placement.

Gas Control

Gases originating within a sanitary landfill which escape directly through the soil cover into the atmosphere are normally dispersed. Gases migrating to confined spaces may create explosion hazards. Gas production in landfills containing active materials is considered to be inevitable; hence, control should be a matter of properly conveying the gases to points of safe disposal.

Methane concentrations of from four to 15 percent in air are flammable. Hydrogen sulfide concentrations of 10 to 20 parts per million (ppm) are considered to be threshold limit values for humans, with a concentration of about 600 ppm reported to result in rapid death (Reference 15). Legal controls should be established and lower limits based on the hazards of a concentration of four percent for methane and 10 ppm for hydrogen sulfide. Proposed legal controls are detailed in "Sanitary Landfill Standard Specifications for Good Practice."

The salient parameters affecting gas production and gas control are the percentage of organic material, the permeability and thickness of soil cover, temperature variation, density, and moisture content. Control efforts will also be affected by factors such as the permeability of the soils underlying and adjacent to the landfill and subsidence. At this time, the control of the passage of gases is considered to be the most practical method of gas control. This can be most effectively accomplished by optimum exercise of the principles of diffusion-dispersion-convection theories. Selected materials, strategically placed, can block, direct, and cause gases to vent to the atmosphere.

The selection and arrangements of systems of materials and methods for gas control have been classified as: (1) peripheral; (2) central; (3) natural; (4) mechanical; (5) internal; (6) external; and (7) combination. Each system should be comprised of a basic and an auxiliary device.

A peripheral system may contain: (1) a trench around the boundary, backfilled with gravel or granular materials; (2) a series of vertical wells spaced around the perimeter; or (3) a combination of trenches, vertical wells, and horizontal perforated pipes. A central system may consist of: (1) a large centrally located granular vent; (2) a system of vertical wells located near the center; (3) a series of trenches located near the center; or (4) a combination of the first three with or without the addition of perforated pipe drains. A natural system could consist of a relatively granular soil cover in comparison to a very tightly grained natural soil beyond the interface. A mechanical system may consist of wells and pipes augmented by power operated exhaust blowers. An internal system is one in which all gases are completely contained and vented within the boundaries. An external system is one in which the gases are not completely contained within the landfill. A combination system is one which is common to at least two of the above. Most systems will be composed of vents, barriers, burners, and blowers.

A vent is a path of minimal tortuosity permitting gas to escape. It may be horizontal or vertical and consists of a ditch or well, backfilled with gravel, or perforated pipe embedded in gravel, if located in a less permeable environment.

A barrier, as the name implies, is an obstruction placed to hinder or totally prevent the movement of gas across a surface. A barrier must either extend far enough so the gas will flow elsewhere or it must be sealed by other barriers in such a manner as to most beneficially direct it. In the design and construction of barriers, the choice of materials is important. The material should be economical, available, easy to install, impervious to moisture and gas, sufficiently inert to maintain its quality under the conditions of the fill throughout alternate wet and dry seasons, capable of meeting the same corrosion requirements as all other underground facilities, and should not be a secondary source of contamination. Soils, especially if available on or near the site, may be economically ideal for barriers. Soil with a large percentage of its grains less than five microns in diameter that has been compacted to 90 percent of its maximum density at optimum moisture content should make a satisfactory gas barrier.

A variety of manufactured materials are available for use as barriers but most have not been tested for impermeability, inertness, and endurance. These materials include polyvinyl chloride sheeting, neoprene, butyl, or synthetic rubber, laminated hot-asphalt-mopped building paper, and others. The softer materials may be damaged during installation and special handling will be required. All sharp sticks, stones, and trash should be removed or covered with fine soil prior to the installation of any flexible barrier. Areas containing grass should be sterilized to prevent vegetation. The area to be covered should be compacted and smoothed to reduce stresses in the membrane, and mechanical equipment should not be driven directly onto the liners unless it is proven that damage will not result.

Ventilation systems can consist of a series of vents connected to a header. For example, at one site a blower was installed resulting in control of the movement of gases within the area of influence of the system. A burner can be installed to control the odors accompanying the gases. Because natural gas, which contains approximately 80 percent methane, will not propagate flame back to the gas supply through a hole less than 0.142 inches in diameter (Reference 16), the burner cover should be drilled with many holes 0.125 inches in diameter.

A gas monitoring program is essential to the proper evaluation of gas production, gas movement, and the degree of success of the gas control system. To facilitate this program, all landfills should have probes at selected locations in sufficient numbers to facilitate a comprehensive testing program.

Subsidence and Differential Settlement

Subsidence is a function of consolidation resulting from the initial compaction of refuse materials, compaction of refuse materials due to overburden, volume reduction caused by decomposition of the refuse, volume reduction caused by saturation with water, the compressible nature of the refuse materials, and volume reduction resulting from removal of leachable materials.

Differential settlement may be defined as nonuniform settlement in the area adjacent to a structure or surface improvement due to consolidation of underlying strata caused by dead and live loads and other phenomena (Reference 17). It differs from subsidence, in that it is less uniform, and is caused by applied forces in addition to overburden of the fill.

The effectiveness with which a sanitary landfill supports its improvements will be a function of the magnitude and timing of its ultimate consolidation and the reliability of any settlement predictions. These may affect the economic life of the development. Engineering control is therefore imperative during the construction of the landfill if a reasonably usable and dependable surface is to result. Minimization of subsidence or differential settlement is dependent on the character, source, and placement of the materials.

Before any portion of a completed surface of a sanitary landfill is used, a certified report should be filed by a soils engineer giving the estimated ultimate subsidence, supporting calculations, and an estimated safety factor. One method would be to require continued subsidence monitoring to generate a subsidence curve from which ultimate consolidation could be estimated. If accurate enough to give the general order of subsidence (e.g. 12 inches or 24 inches or 48 inches), this should be adequate for the purposes of funding for maintenance or repair (Chapter VI). Another method of approximating ultimate subsidence would be to synthesize the landfill, if built under controlled conditions, to a laboratory scale and performing the ultimate subsidence prediction experiment (Chapter II).

The condition of the finished surface of the landfill will be dependent upon conditions at each finished surface at the top of each lift within the landfill. If compaction of the intermediate lifts is not maximized this will have an effect on the ultimate use of the landfill. Any daily cover which is not properly compacted should be recompacted prior to subsequent filling. The most successful minimum thickness of daily cover reportedly minimizing odors and vectors appears to be about one foot. A firm recommendation of daily earth cover should be based on individual characteristics of the selected cover soil and its moisture content. At this time, one foot is recommended as a desirable compacted thickness for cover with inert material at the end of each working day. However, operations occasionally filling to depths of less than three feet may be jeopardized by the economic feasibility of a ratio of three feet of lift to one foot of daily cover. For this reason, operations filling to a compacted depth of less than three feet daily could be allowed to proportionately reduce the daily earth cover, but the daily earth cover should under no circumstance be less than six inches.

The minimum final cover for the entire landfill is recommended to be three feet. In no case should any permanent excavation reduce the cover to less than three feet.

Maximized initial compaction coupled with minimized heterogeneity should result in the earliest ultimate consolidation. Surcharge loading applied to sanitary landfills will accelerate early consolidation. Volume reduction caused by biological decomposition may be expected to result from wetting of the refuse (Reference 7). The addition of water, to an appropriate moisture content, to refuse and cover material may be expected to provide the earliest ultimate consolidation. However, the addition of water to a sanitary landfill should be carefully controlled. Excess water in the interstices may be avoided by providing for drainage over finished cells, intercepting surface waters adjacent to the cells, and installation of subsurface drainage facilities.

The installation of sumps, septic tanks, and leaching systems, because they depend on dissipation of liquids within the landfill, should be prohibited. All sanitary facilities, with the exception of approved chemical toilets, should be connected to an approved closed sewer system.

Side slopes normally considered to be adequate in inert material should be considered as excessive where underlain by active material. The danger of sloughing may affect the security of buildings or structures in the path of the sloughed material. This is most likely to occur where structures parallel the toe of the slope or the top of the slope of a sanitary landfill.

To minimize sloughing, which would result in removal of lateral support from the landfill cover, a desirable average slope should be three (horizontal) to one (vertical). Where the horizontal distance from the footing to the top of the slope is less than three times the depth of the final cover, sloughing should be expected and protection should be required. If a projected line of the slope past the toe of the slope extends beyond a building line near the toe of the slope, slough protection should also be required. This slough protection may be provided within the landfill by the placement of inert embankment or masonry cutoff walls.

The construction of a sanitary landfill should be recorded or logged. Topographic control within a few tenths of a foot, after each lift operation, would ascertain the elevation and slope of each daily cover.

If special areas within the landfill have been set aside and approved for nonconstruction areas, special items that would be otherwise inadmissible should be acceptable. A special record should be kept of the refuse deposited in that area. For example, large solid items, such as construction residue and heavy metal objects in excess of 36 inches in dimension, should not be accepted within any portion of a landfill that has been designated for future structures requiring piling foundation.

Monitoring of the vertical movement of the individual levels of daily cover could be of benefit to eventual determination of the utility of the site. During construction of the landfill, risers could be installed that could be extended to the completed surface for subsidence monitoring surveys. Irrespective of the methods for providing for it, subsidence monitoring of the finish grade should be conducted and referred to at least two permanent bench marks coordinated to a control loop of the United States Geological Survey. Each subsidence monument should be located within a vertical loop and a horizontal coordinate system, mapped, and checked at regularly prescribed intervals. The maximum distance between monuments within the sanitary landfill boundaries is suggested as 200 feet and in lieu of the possibility of a regular pattern a system of four per acre should be satisfactory. A meaningful subsidence program can be established by measurement of subsidence monuments at periodic intervals of three to six months, depending upon the rate of subsidence.

CONSTRUCTION

Permitted Materials

Materials, Class I are defined as any solid or liquid waste. Materials, Class II are defined as any solid waste that contains no hazardous substances but is comprised solely of ordinary household and commercial refuse and/or rubbish, garbage, other decomposable organic refuse, and scrap metal of the nature of the following general materials: (1) empty tin cans; (2) metals; (3) paper and paper products; (4) cloth and clothing; (5) wood and wood products; (6) lawn clippings, sod, and shrubberies; (7) hair, hides, and bones; (8) small dead animals; (9) roofing paper and tar paper; (1) unquenched ashes mixed with refuse; (11) market refuse; (12) garbage; and (13) all materials, Class III. Hazardous substances are defined as those wastes such as, but not limited to, toxic materials, explosives, and highly flammable wastes which require special handling to avoid illness or injury to persons or damage to property. Materials, Class III are defined as solid waste that contains no hazardous substances comprised solely of nonwater soluble, nondecomposable, inert solids of the nature indicated by the following general materials: (1) earth, rock, gravel, and concrete; (2) asphalt paving fragments; (3) glass, ceramics, and inert plastics; (4) plaster; (5) manufactured rubber products; (6) steel mill slags; (7) clay and clay products; and (8) asbestos shingles. Most materials, Class I should be acceptable at any Class I site. However, hazardous substances should be excluded unless approved disposal methods are employed. Radioactive wastes should not be accepted at any sanitary landfill. Materials, Class II should be acceptable at Location, Class I and Class II sites. Class III materials should be acceptable at all sites.

Nonhazardous liquids should be acceptable at Location, Class II sites, if utilized as a moisture ingredient to aid in solid waste compaction and spread in that manner.

Some of the purposes of the cover are to control noxious odors, inhibit access of pests and vectors, and improve the appearance of the landfill. The cover should be free from putrescible matter or large objects, be well compacted, and not subject to excessive cracking or erosion. When sandy loam soil is used, a tight cover can be provided and economically maintained. Materials considered to be less suitable for sanitary landfill covers are silts, clay loam, sandy clay, silty clay, sand, organic soil, incinerator residue, fly ash, and diatomaceous earth.

Certain materials require special handling to be acceptable for use in landfills upon which the construction of improvements may be included. These materials include sewage wastes, large dead animals, products of abattoirs, wastes from poultry hatcheries, and significant quantities of semi-solids or semi-liquids from any commercial or industrial operation. Water softening residues and abandoned vehicles could be permitted under limited conditions that include no risk to usable waters. Other limits to inclusion of abandoned vehicles should be to locations planned as green space, and to areas upon which no improvements are planned or will be built. The interspersion of solid water softening residues with normal sanitary landfill wastes may be acceptable; however, if the water constitutes a major proportion of this type of waste, it should also be set aside in an area for future nonimprovement. Because of the flammability of oils, greases, and fats these wastes should not be accepted in abandoned coal mines or coal pits. Hazardous materials in general should be excluded.

The sizes of objects in sanitary landfills may be important. The major objection to a large solid nondecomposable object would be that it may represent an obstacle to subsurface exploration or drilling for deep foundations. If the same size object is highly decomposable then it would represent a potential anomaly in the prediction of ultimate subsidence of the landfill. Uniformity of settlement requires a limit on the size of acceptable materials. This limit may be arbitrarily set at 36 inches maximum dimension for any one object placed at random within a portion of the sanitary landfill. However, an exception should be provided for portions of landfills planned to be utilized only as green space or in deep canyon landfills. Baling operations providing packages 72 inches in the largest dimension are acceptable but there should be a limit on the largest object in the bale and it is proposed to limit this size to 36 inches. Bulky, heavy materials, such as concrete or bricks, should be placed at the bottom of the the fill and not in the top or sides where they may provide an unwanted surcharge effect, create increased heterogeneity, and provide harborage for rodents.

Excavation, Grading, and Drainage

As rapidly as solid waste is admitted to the site it should be spread and compacted in layers so that after track or roller compaction the layer should not exceed two feet in depth. This is not possible in all cases in Class III Materials. The rubble comes in much larger sizes and should be permitted to be deposited deeper than 50 feet below proposed finish surface or in an area approved for future nonimprovement. In deep canyon fills larger objects should be permissible. Any portion of a deep fill deeper than 200 feet below proposed finish surface should accommodate objects such as tree trunks and relatively decomposable materials without causing or contributing to future problems.

The surfaces of completed shallow landfills in urban areas may be reasonably expected to be more in demand for use than the surfaces of completed deep canyon landfills. The difference between subsidence of a refuse landfill and an ordinary inert fill is due to the ratio of inert material to active material. As the proportion of active material increases subsidence will increase. In deeper landfills the overburden will contribute to consolidation of the materials placed near the bottom. Nearer the top the overburden will be less. Based on this premise, the maximum lift height of active materials should be a function of the remaining fill depth or height. For depths of from 0 to 20 feet to the bottom of the final cover, a lift height of more than three feet would create an inordinately large proportion of active material to inert material for a shallow landfill. From the following table, for a maximum lift height (h), for each remaining fill depth or height (H), it can be seen that the ratio of active material (based on one foot intermediate cover between lifts) to inert material varies from three to one in the shallowest landfill to 20 to 1 in the deepest landfill. The least percentage of lift height to remaining fill height varies uniformly from 15 percent in the shallowest landfill to five percent in the deeper landfills. On this basis, the following maximum allowable lift depths should be considered:

H (feet)	h (feet)	Minimum Percent (h/H)
0-20.0	3	15
20.1-50.0	4	8
50.1-75.0	6	8
75.1-100.0	8	8
100.1-200.0	10	5
200.1-300.0	15	5
deeper than 300.0	20	5 (if H = 400)

In order to minimize blowing papers and attraction for pests and vectors the working face should be limited to 150 feet in length per bulldozer and should be no wider than is necessary for the proper and convenient operation of the spreading and compacting equipment. The daily cover should be placed to form a completely enclosed cell containing the compacted refuse during a single day's operations. A daily cover should not be allowed to remain more than 120 days unless a final cover has been applied.

The final cover should be in place and compacted over any completed portion of the landfill prior to a rainy period, if possible. During periods of precipitation, cover should be applied as rapidly as possible after refuse filling. Due to subsidence and its effect on drainage, two percent should be the minimum final slope upward from the point of minimum elevation. Four percent is the recommended maximum slope.

All finished slopes should be analyzed by a soils engineer for stability. Until research, testing, and evaluation proves otherwise, the steepest average side slope on a sanitary landfill should be 3 (horizontal) to 1 (vertical). This average slope includes the beaches characteristic of this type of grading. The resultant maximum side slope of any finished surface will vary between 2.4 to 1 and 2.7 to 1.

Finished landfill surfaces will require drainage protection in the form of benches, interceptors, and planting. Ordinary construction equipment requires a minimum width of eight feet. Paved interceptor terraces in filled slopes should have a minimum width of eight feet at intervals not to exceed 25 feet measured vertically. Filled slopes higher than 50 feet, measured vertically, should be provided with horizontal benches with a minimum width of 15 feet. Terrace drainage should be provided with slopes adequate to drain under most subsidence conditions but with slopes less than that which would contribute to erosion. These slopes should be designed for the tributary drainage area with a flow of not less than four feet per second nor more than eight feet per second. In a landfill comprised of combined cut and fill slopes exceeding 25 feet in height, the required drainage interceptor should be placed at the top of the cut slope.

All finished slopes should be planted and irrigated to promote the growth of ground cover plants to protect the slopes against erosion. Preparation of the fill slopes may be accomplished in one of three ways:

(1) The slope surface of the fill may be prepared by placing top soil over the slope surface. A top soil layer of three inches should be adequate in most cases.

(2) The slope surface may be scarified to a depth of approximately three inches.

(3) Loose earth, in a depth not to exceed three inches, may be left on the slope.

The most dependable water system is considered to be the sprinkler system but this is not practical in all cases. In some cases hand watering may be practical. If adequate water lines are installed to conveniently located hose bibs and if hoses are not longer than 100 feet then sprinkler systems may not be necessary.

Operations

In general, it is more practical for the operator to be represented during filling operations than for the local governing authority. Therefore, the operator should assume all responsibility for operation and security. In order to accomplish this, a responsible representative should be available at all times.

In order to respond to proper authority, a daily log of all operations should be maintained. The log should include: the quantities and types of refuse accepted each day, placement, and lift heights; unusual occurrences; all applications of water, precipitation, and chemicals; the numbers and responsibilities of employees on the job; and the type and use of equipment used on the site. In order to communicate with the representatives of the local governmental authority it may be necessary to provide for the submittal of periodic reports. This should be the prerogative of the local governmental authority.

Precautions should be instituted to prevent the ignition of any material on or in sanitary landfills. In the event of a fire there should be a means of communication between the employees and the site office and the local fire department in the form of radio and/or telephone communications. Standard safety equipment on vehicles should include Fire Underwriter's approved hand extinguishers.

Because the public will be dependent upon the landfill, all legally qualified refuse that is brought to the site which is not in excess of capacity should be accepted. Reclamation and reprocessing operations (away from the sanitary landfilling site) should be encouraged to enhance the economic desirability of landfilling. Metals can be reclaimed for their reuse. Paper, fibreboards, and rags may be reprocessed into paper forms of lower economic value. Glass salvaging potential on a mass commercial basis is currently being investigated. These and other reclaimable items that may be removed will tend to diminish heterogeneity and minimize separation and bulk problems. Reclamation or reprocessing should not be a health or operational hazard.

All weather, dust free access roads from the point of entry to the face of the landfill and staging areas should be provided and maintained so that vehicles waiting to enter the landfill area will not impede the flow of traffic on public streets. There should be a space provided for turn arounds to reroute vehicles not authorized to enter the landfill. Clearly marked directional signs should be at all times located prominently to properly direct traffic. "No Smoking" signs should be posted at all entrances to and within the facility.

Where trucks deposit rubbish at the working face by backing to the top of a grade of a slope of 2 to 1 or steeper, a bumper, curb, or tiedown, sufficient to give warning of the approaching edge and impede the motion of the truck should be installed.

Clean sanitary toilet facilities should be provided on the premises for all employees. A first aid kit, equipped with sterile bandages, antiseptic solutions, tourniquets, splints, and other necessary supplies should also be available. All operations which extend beyond daylight hours should be equipped with night lights. Common shelter and heating should be provided as necessary.

CHAPTER VI

CRITERIA FOR THE INSPECTION, SUPERVISION, AND MAINTENANCE OF SANITARY LANDFILLS

INSPECTION

Inspection of sanitary landfills and improvements by a qualified deputy authorized by the local governmental agency is necessary to implement regulatory requirements. The inspector should have the authority to determine the effects of the completed work upon the planned objectives and the likelihood of danger or inconvenience to any person or property. He should have authority to order work stopped if he detects a dangerous or illegal condition. This should be done in a manner that is fair to the involved parties and because of the nature of dependency of the public upon the landfill and for administrative reasons all work stop orders upon landfilling operations should be written. If adequate precautions or corrections to hazardous conditions can be taken, work should be allowed to proceed.

During the course of any construction project various interpretations may be placed upon the plans and specifications. Depending upon the magnitude of the conflict with the approved plans either immediate corrective action or corrected plans may be necessary. Cautious judgment should be exercised but if danger impends, the inspector should have the authority to order the work stopped until it is corrected or until revised plans have been submitted and approved. If the operator or permittee fails to submit the required plans, or to provide protective measures then action should be taken. If an applicable bond exists, action upon the bond may be taken. If no bond exists to cover the situation, the governmental authority may have to resort to available civil recourse.

Sanitary landfill operations should be inspected as often as necessary to accomplish regulatory objectives. However, continuous inspection by a public agency is uneconomical and may be avoided if clearly defined permit requirements are established. The data flow pertaining to the operations can be somewhat continuous if a daily log is kept by the operator. If a violation is detected the pertinent facts should be recorded on a report form and a copy left with the landfill supervisor. A copy should also be filed in the inspector's office and, after an appropriate and reasonable time, a second inspection should be made to determine if the violation has been corrected. In the event of continuation of the violation then an action may be required to suspend or revoke the permit, or if necessary, take a legal action upon the bond. Records of the operations should be required and accessible to the inspector at normal times. Should the need arise the inspector should have authorization to copy these records.

Structures on and adjacent to a sanitary landfill should be inspected to secure compliance with or to prevent violation of provisions of any applicable ordinance. Additionally, the owner or his authorized agent should be allowed to enter the building when necessary, to carry out any instructions, or to perform any work necessary to assure compliance with any code. During the absence of the occupant, entry should be effected only with a court order. To obviate the possibility of unnecessarily enforced inconveniences upon the occupants of the building reasonable hours should be established for access.

Surface improvements on a sanitary landfill should be inspected as often as necessary during or subsequent to construction. Survey markings, rough and finish grades, construction procedures, materials, and safety procedures or equipment are critical items that will affect the construction and operation of streets, sidewalks, curbs and gutters, drainage ditches, driveways, or works constructed to be of service at grade. Access to surface improvements is not normally a special problem but should be guaranteed by regulation.

Subsurface improvements in or adjacent to a sanitary landfill should be inspected as often as necessary during and after construction to ascertain whether such facilities are properly constructed, operated, or maintained.

SUPERVISION

All construction activities on a sanitary landfill site should be responsibly and continuously supervised. Sanitary landfill operators should provide sufficient supervisory control during grading and filling operations to assure safe, prompt, and economical compliance with the approved plans and applicable laws and regulations. At times, supplementary engineering or geological services will be required. These services should be provided at the expense of the landfill operator.

Special conditions may require the submission of reports. These should be provided and certified by the supervisor responsible for the particular work item. Certification for that portion of the work concerning the preparation of an existing ground surface and placing and compacting of required inert fills should be made by a soils engineer. Geological conditions should be reported by a geologist and the assurance that all geological conditions have been adequately considered and recommended measures taken should be so certified. The coordination of all reports and facture during the landfilling operations should be the responsibility of the operator or his designee. It is also incumbent upon the supervisor, when finding that major work is not being done in conformance with the requirements, that he immediately notify the person doing the work and the proper authority in writing of the noncompliance and of the corrective measures that were taken or recommended.

Structures designed under special provisions of applicable local building codes may require continuous supervision due to special techniques, provisions, or utilization of maximum range stresses. It is also possible that the landfill official and the Chief Building Official may have bilateral responsibilities for construction on sanitary landfill surfaces. If so, the architect or engineer responsible for such design should provide written certification to the landfill official that each structure or portion thereof requiring continuous supervision was constructed in conformity with the approved design. Certification should include the dates of the supervision, the name and professional designation of the supervisor, and descriptions of the work requiring continuous supervision.

The design of surface improvements should include the responsibility for supervision by the engineer who prepared the plans and specifications. The engineer should certify in writing to the landfill official that the surface improvements were constructed in conformity with the approved design.

Subsurface improvements are of varied character and generally may be designed by either a civil engineer, mechanical engineer, or an electrical engineer. The design engineer should certify in writing that the construction is in conformity with the approved design. Certification should include the name and professional designations of supervisory personnel, the dates of supervisory activity, the description of the subsurface improvements, and problems that were encountered during the construction of the subsurface improvements, and on the disposition or solution of the problems encountered.

MAINTENANCE

Landfill slopes should be constructed to drain water and all cover should be as impermeable as possible after compaction. During operation of the landfill, the materials within the lifts should be protected from intrusion by surface waters and the neighborhood can be protected from emission of odors and attraction to pests and vectors if a tight cover is maintained over each lift. The final cover may be expected to subside and endure cracks, thus impairing drainage slopes and possibly resulting in ponding. Filling and scraping of the affected surfaces will be necessary to alleviate or prevent ponding and maintain the integrity of the cover.

Ground cover vegetation is required to stabilize the surface. The effects of erosion on ground cover vegetation may be minimized by replanting similar or more stable species. Monitoring devices may also be affected and these should be protected as much as possible and repaired or replaced as they become damaged, lost, or destroyed. Records should be kept of the disposition of all monitoring equipment. An up-to-date map is the most convenient and informative record for bench marks, subsidence monuments, gas probes, and well points.

Motorized equipment on the landfill site should be kept in functional condition. Auxiliary equipment should be available for peak loads or emergencies during all operating hours. Noises and fumes from motorized equipment should be minimized. Maintenance activity should be located and timed to improve operational efficiency. In many communities sheds for storage and maintenance of equipment will be required because of climate, security, or even aesthetic desideratum.

The integrity of each gas control device should be maintained to effectively perform its required function. Gas barriers may be impaired by stretching or breaking due to strains induced from a variety of causes including subsidence and differential settlement. Patching may be feasible in some instances. Gas vents may be infiltrated by materials reducing the areas at flow sections thereby decreasing effective flow. Corrective measures may include flushing with water or blowing out with compressed air. Exhaust fans and circuitry may be affected by dust and corrosive influences. Parts may need replacement.

Monitoring and analysis of gas concentrations should be required until gas production declines to a safe level and remains safe over a measured period of time. The results will be an indicator of the effectiveness of the design, construction, and maintenance but more important, will be fundamental in causing corrective action. The monitoring should be done under supervision of a qualified engineer.

Odors may be masked chemically or the cause may be corrected. Chemicals applied to landfills should be cautiously evaluated prior to approval for their use. Active material should seldom, if ever, vent directly to the atmosphere. Odors resulting from this condition may be sealed off by placement of a compacted soil cover.

Regular periodic inspections should be made for signs of rodents and winged pests. Appropriate steps should be taken, if necessary, to improve or correct conditions fostering their presence. Rodenticides and insecticides should be used as necessary as part of a program but their use should be supervised and subject to approval from health authorities prior to application.

CHAPTER VII

CRITERIA FOR THE USES OF LAND ON AND ADJACENT TO SANITARY LANDFILLS

THE GENERAL PLAN

The uses of all lands should remain principally a function of the general plan of each individual community. However, landfilling and its associated phenomena should be considered when preparing the general plan. Land uses concentrating people in confined spaces on or near landfills should be avoided if the possibility exists that accumulating gas concentrations (1) measurably reduce breathable oxygen-in-air percentages; or (2) poison the air to human, animal, or vegetable life; or (3) result in explosive or flammable atmospheric conditions. Engineering and construction feasibility should also affect land use planning.

The best possible completed landfill surface cannot be expected to provide the stability required for heavy structural and traffic loadings. However, properly planned, completed landfills in the future can be useful for heavier loadings than would have been possible without exercise of meaningful criteria.

The street and highway plan is a component of the general plan that could remain unaffected by the reuse of the sanitary landfill. The use of the completed landfill surface can comply with the street and highway plan by planning for essential rights-of-way and improvements as part of the landfill construction (Chapter VIII).

Codification will provide legal implementation. Use of a sanitary landfill code will assure that the necessary precautions will be properly determined and implemented to reserve and utilize completed landfill areas in conformity with the general plan.

USES OF COMPLETED SANITARY LANDFILLS

The surfaces of those existing or completed landfills, upon which there is no prospect for successful development requiring extensive improvements, should be controlled by statute law to facilitate compatible uses. The potential uses for these landfills should be limited to park and recreation use, open assembly areas, temporary heliports, or other uses with minimal or no improvements.

Some existing completed sanitary landfills may have been planned and constructed to minimize the problems due to settlement and subsidence. Such landfills may be acceptable for planned use, if they can be provided with suitable gas controls. They should, of course, be subject to all engineering and governmental regulations and should not be used for any purpose not allowed on proposed landfills.

A gas monitoring and analysis program is the best practical method of determining the existence and extent of hazard from gases. If gas concentration histories and refuse core sample analyses indicate a long-term decrease in methane production potential, construction of enclosed occupancies without gas control systems may be permissible. However, detection of hydrogen sulfide in amounts of 10 parts per million or greater should be sufficient to restrict human habitation on the property.

Where there is the remotest possibility that gases may migrate to and concentrate in confined areas or rooms, human use should be prohibited or the building should be designed to prevent the entry of gases.

USES OF LANDS ADJACENT TO SANITARY LANDFILLS OR DUMPS

Uses of lands adjacent to existing sanitary landfills or dumps may be subject to considerations different from those for future landfills. An indefinite number of uses encroach upon lands adjacent to existing dumps and sanitary landfills. The degree of conformity to safe standards can be determined by monitoring gas concentrations. Residents of lands adjoining existing landfills should be made aware of the potential hazards, if any, and the degree of hazard, if determinable. Closed habitable construction on adjoining undeveloped and uninhabited lands should be subject to a minimum separation distance. A reasonable minimum separation distance between a sanitary landfill interface and adjacent closed habitable structures is recommended as 1,000 feet.

Because of uncertainties with respect to geological and engineering potential at the time of planning it may not be practical to exercise exceptions in many cases. However, as time passes and more is known about individual sites and the development potential in the vicinity, the highest and the best use of the land adjacent to existing landfills may be determined. In highly paved areas or in areas where grading operations have tightly compacted the soil surfaces surrounding the landfill, gases may be forced to move even greater lateral distances in order to escape to the atmosphere. Knowledge of these conditions might warrant increasing the required separation distance. Knowledge of favorable soil permeability and geologic conditions or of the construction of adequate gas control devices may favor the relaxation of the separation restriction at the time that planning is implemented or at the time a permit is sought.

CHAPTER VIII

CRITERIA FOR THE DEVELOPMENT, CONSTRUCTION, AND MAINTENANCE OF IMPROVEMENTS ON, IN, AND ADJACENT TO SANITARY LANDFILLS

INTRODUCTION

Although each site should be planned on the basis of specific merit, it is generally best to plan for the use of a completed sanitary landfill as a park, a golf course, or an open space. However, in the event that construction on a sanitary landfill is being considered, this chapter presents suggested criteria for the designer of the landfill improvements.

The following construction techniques and precautionary measures are not intended to be complete solutions to landfill problems, but are presented to provide a basis upon which further specialized engineering thinking can be applied. It should be noted that the precautions and special techniques necessary for building on a sanitary landfill will increase the cost of the construction accordingly.

FUNCTIONAL REQUIREMENTS

Gases generated within a sanitary landfill migrate horizontally, upward, and downward, often intruding into adjacent properties, accumulating in confined spaces, and causing health and fire hazards. The design of any improvement on, in, or adjacent to the sanitary landfill should exercise cognizance of this situation. This may be accomplished by constructing barriers, vents, or a combination barrier and ventilation system to inhibit the intrusion of gases in specific locations and selectively provide for their emission.

Regulation is necessary to control gases during and after landfill construction. Those mechanics by which gas migration can be prevented prior to landfill construction are described in Chapter V, "Location" (of Sanitary Landfills). During landfill construction, gas control may be accomplished as described in Chapter V. After landfilling, minimization of confined spaces may be effected during the design of the improvement.

The behavior of the ground surface upon which the structure is placed affects the capability of the foundation and consequently its service performance. Service performance estimates may critically affect economic feasibility determinations.

IMPROVEMENTS

Gases may be prevented from entering improvements by utilizing gas control barriers and vents of proper material in propitious locations. Acceptable alternatives for barrier materials include: vinyls, copolymers, terpolymers, building paper, and water stop materials. Gas vents may be required around the periphery of the structure, in plumbing access spaces, and electrical panels. A gas control system around the building may be comprised of trenches filled with granular material, perforated pipe drains, combination vent stacks, and holes in the foundation walls. Figures VIII-1, VIII-2, and VIII-3 show the respective design examples of a foundation vent, barriers under slabs, and underfloor vents. Utility entries should be especially protected to prevent gases from following permeable trench bedding and venting into confined spaces. Collars and connectors to seal off gases may be fabricated from film and adhesive which can be glued to liners. Figure VIII-4 shows design examples of entry conduits.

The most pronounced differential settlement generally will occur under buildings founded partially on inert material and partially on sanitary landfills. Any building thus designed for this condition should be analyzed for differential consolidation and its anticipated time, bearing capacity, and the maximum shear value at the interface.

The major effect of differential settlement on surface requirements of structures is to impair the initial conditions of level and vertical alignment and to produce corresponding horizontal loadings. Although the most effective controls on landfill construction will not produce a surface over a sanitary landfill cell as stable as a surface over an inert fill or on natural ground, certain alternative foundation choices exist which aid in maximizing structural stability. These alternative foundation choices, in order of preference for structural stability, are: (1) piling; (2) raft foundations; (3) continuous footings; and

(4) spread footings. Major parameters in design considerations are twofold: consolidation-time-settlement relationships; and load and bearing capacities, developable from field and laboratory tests.

Under buildings located totally on a sanitary landfill, prediction of the plane at which differential settlement will occur is more complex because this plane might locate anywhere under the foundation wall. To anticipate this problem, the magnitudes, locations, and directions of additional stresses, due to these distortions, should be predicted and resisted.

The bearing capacity, determined as a maximum over a sanitary landfill cell, should be divided by a factor of not less than 1.75 to calculate a recommended working bearing capacity for design of foundations. This is because, over a period of time, the relative vertical movements of identifiable fill volumes, with respect to each other (when combined with relative horizontal movements), may ultimately result in stress concentrations to foundation soils, greater than the initial design and construction conditions. Under no circumstances should occupancy be permitted in structures where the ratio of allowable working stress to actual stress decreases to less than 1.0.

Foundation design incorporating differential settlement at any potential location may be simplified by assuming that the removal of support at selected locations may occur in the following variations: (1) the ends settle more than the middle and humping causes tension stresses in the top accompanying shear stresses, and resultant moment effect; (2) the center settles more than the ends and sagging causes tension stresses at the bottom, compression stresses at the top, and resultant shear and moment stresses; (3) support under one end ceases to exist and a cantilever effect causes tension stresses at the top, compression stresses at the bottom, and resultant shear and moment effects; and (4) gradually increasing settlement from one side of the structure to the other tilts the entire structure altering the stress paths and combinations.

Proper structural design must, of course, include the assessment of all potential loading. These loads will be transmitted to the sanitary landfill by the foundation and may be classified into vertical and horizontal loads. Vertical loads are those imposed through gravity by the weight of the structure itself, and those loads which are imposed by the conditions of use. Horizontal loads, also called lateral loads, may be the result of a force effect induced by vertical loads asymmetrical with the elastic center of resistance incurred by differential settlement. Foundations with low internal shearing stress may thus be subject to lateral loading as a direct result of vertical loading.

The primary structural components which will be affected by the foregoing phenomena are slabs, piling, raft foundations, walls, connections, and, in the case of rigid structures, the total structure concept. A slab installed over a sanitary landfill cell and transmitting loads directly to it may behave more as a membrane than as a slab. To eliminate this, slabs poured directly on the surface should be stiffened by engineering monolithically cast beams in two horizontal directions at right angles to each other forming a two-way ribbed mat. Two-way ribbed mats on sanitary landfills should be designed for the worse cases of settlement such as the settlement of two adjacent column lines with the slab spanning the clear distance.

The floor slab design should also include the possibility that the slab will tilt and, although expensive, provisions should be made for jacking, grouting, or otherwise releveling the slab. Any releveling devices that are incorporated into the mechanical or structural design should also be designed for the potential vertical and horizontal loads. Slabs bearing directly against the final cover adjacent to piling will transmit loads directly to the fill and add to the piling loading.

Piling penetrating the active portion of the sanitary landfill should be designed for all vertical and horizontal loading, the down drag effects of frictional resistance to subsidence and settlement, and any floor loads transmitted directly to the fill adjacent to piling. The vertical loads can be resisted by bearing at and/or friction in the soils underlying the landfill. The possible effect of leachate, reducing the allowable friction value in clay-like soils, should be considered. Horizontal loading can be resisted by developing a horizontal load resistance in battered piles or in moment connections at the tops of the piles. Dead-man design is not recommended, as it may induce gross horizontal displacements. Figure VIII-5 is a design example of footings.

Raft foundations upon which the total stability of the structure is dependent are less desirable than piling foundations, but may be permissible. If a selected foundation site has satisfactorily demonstrated a capacity to support the necessary dead and live loads it should be acceptable for a raft foundation. This may be demonstrated by surcharging the site and monitoring the subsidence after decomposition has effectively ceased.

An increase in shear results from the horizontal torsion caused by eccentricity between the center of mass and the center of rigidity. These shears should be resisted. A symmetrical structure which settles differentially could cause this eccentricity. The shear resisting elements should be capable of resisting a torsional moment assumed to be equivalent to the story shear acting with an eccentricity of not less than 5 percent of the dimension from exterior bearing to exterior bearing.

Spread footings and pads should not be permitted to rotate. Rotation can be inhibited by monolithical struts. Continuous and spread footing designs should be proportioned for slow, long-time settlement. This may be done by balancing a principal footing design for the maximum calculable allowable soil pressure (based on the minimum allowable footing size for full live and dead loads) then designing all other footings for that maximum allowable soil pressure when loaded with full dead load plus one-half live load (Reference 18).

Under select span and width conditions, it would be advantageous to utilize rigid building walls as deep girder foundation elements.

For the purposes of the following discussion, a surface improvement is a street, driveway, sidewalk, curb, gutter, open ditch, or open channel, or any portion thereof constructed to be of service at grade. Surface improvements are not likely to trap gas; nevertheless, a complete criteria would dictate that gases should not be allowed to concentrate in confined areas of surface improvements. Inherent in the previous statement is the assumption that manholes be classified as subsurface improvements. Unless they are damaged it is not likely that catch basins which are open to the surface could become anything more than a vent providing for the release of gases.

Surface improvements are more likely to be damaged by the effects of differential settlement or subsidence. Surface channels, ditches, and drains that might settle unevenly will have their hydraulic characteristics impaired. Design alternatives include either design for the conditions accruing from subsidence or differential settlement or design to prevent differential settlement. In the first instance, flow lines may be designed at the steepest subcritical slope, that slope above which critical velocity occurs. Subsequent flattening of the grade might result in uneven deposition of solids but need not impair the overall function of the drain. It should be recognized in the design that slopes may become supercritical and therefore freeboard should be provided in the event that hydraulic jump occurs. Overlapping sections of reinforced concrete or flexible metal may represent an acceptable settlement provision. The alternatives, of course, are to provide inert or structural support or span between such supports. Alternatives which accept settlement or provide for mitigating the results thereof should be backed up with maintenance funding.

Drainage channels which are provided with overlapping sections may be undercut by eddying currents. At the points of overlap, subsurface cuttoffs or checks should be provided at right angles to the flow line and also parallel to the flow line. This design may be incorporated to provide supports for the drainage channel sections.

Swimming pools on completed landfills were found to be a special problem unless founded on piling. Swimming pools should be founded on piling if not constructed on inert material but in the event that surcharge loading has been applied and subsequent testing indicates the ultimate consolidation would have little or no adverse effect, then a swimming pool founded on an approved raft foundation or a two-way ribbed mat may be acceptable.

When possible, streets should be founded on inert material. This can be accomplished by means of preplanning if the cost of building a high inert embankment does not render a landfill operation uneconomical. Streets built on a landfill with an optimized ratio of solid waste to inert material should be of asphalt concrete thus flexible and able to sustain light automobile traffic loadings.

The "Design Traffic Number" is the average number of equivalent 18,000 lbs single axle loads per day expected in the heaviest traffic lanes during a period of about 20 years (Reference 19). A design traffic number of 4.8 or less, if applied to standard road bed design, would result in a suitable structural cross section. However, single axle loads of 18,000 pounds should be prevented from actually driving on the road so that the service life of the roadway may accommodate the equivalent in light traffic loading. The design for all traffic loads should be based on the strength value of the supporting materials. It is therefore reasonable to exclude heavy traffic design loads from surfaces over sanitary landfills unless the results of comprehensive borings and consolidation testing determine that such loadings are feasible. In the absence of scientific criteria, streets which carry traffic loads heavier than a "Design Traffic Number" of 4.8 should be built on inert material.

The design of concrete curbs, gutters, and sidewalks may be modified to provide horizontal spans with maximized resistance to horizontal and vertical loading. If constructed monolithically, an edge beam at the edge of the sidewalk opposite to the curb at the other side of the sidewalk could approximate a symmetrical load carrying member that may be analyzed as a horizontal beam and diaphragm. Vertical and battered piles might be used to deliver the horizontal and vertical forces to the original ground.

During the data survey phase of the study it was discovered that surface improvements such as utility poles, fences, street signs, and similar improvements lost their plumb due to subsidence. Utility poles set in concrete bases with adjustable anchor bolts and nuts are common. This releveling device is recommended. Some poles may be releveled by the use of adjustable turnbuckles and cables, but individual ingenuity may also be required in certain design situations (Figure VIII-6).

A building not founded on piles probably will settle more than the surface improvements. A building founded on piles will settle less than surface improvements over landfill cells. In both cases, flexible connections should be required between the building and the surface improvement.

Subsurface improvements in juxtaposition to surface improvements and structure improvements will be subject to the same peculiarities of gas control and subsidence and differential settlement. The requirement for control of gases of various origins in subsurface improvements is historical and is attested to by numerous utility companies and municipalities. Within 1,000 feet of the boundary of a sanitary landfill persons preparing to enter a substructure should first test for the presence of gas.

Particular attention should be directed toward the design of pipe bedding. Granular materials convey gases but may be acceptable if vertical barriers are built into the bedding between manholes, in the form of concrete saddles or cradles. Plain or reinforced concrete bedding is effective for gas control but it imposes an additional load on the supporting landfill (Figure VIII-7).

Subsurface improvements are susceptible to the effects of differential settlement under conditions which are usually difficult to detect. Placing utility lines in an openable trench may be one solution to the inspection problem. The lines could be supported on adjustable shims on the bottom of a paved trench and the cover could be optional. Utility lines might be protected from overburden loading by placing a metal corrugated arch over and to the sides of them and backfilling over the arch.

When a line sags it lengthens. Electrical and fluid carriers not dependent on alignment but whose impairment is incurred by stretching or breaking might be placed in a horizontal zigzag manner up to maximum allowable manufacturer joint deflection. Ball and socket joints of cast iron pipe are expensive but they might also be used to accommodate differential settlement.

At the entry of utility lines through foundation walls, hangers and turnbuckles could be installed to support the utility lines and allow for adjustment within the limits of the sleeves. Flexible sections at such interfaces have also been successfully used. As with surface improvements designed to carry liquids, underground gravity lines could be designed at the steepest subcritical slopes with freeboard which might include additional diameter or pressure-momentum design capacity.

The design for all underground piping should be conservative. Upon experiencing subsidence or differential settlement it is possible that the the factor of safety will diminish, but as long as the ratio of allowable stress to working stress remains greater than 1.0 the lines can be considered eminently serviceable.

Monitoring of the subsidence of underground lines can be facilitated by the provision of risers, to the ground surface, marked with permanent brass caps upon which are inscribed the purpose of the monumentation. Lines in openable trenches or lines fitted with automatic shutoff valves in the event of service interruption could be exempted from this provision.

Prior to placement in the sanitary landfill any subsurface improvement that might come in contact with active materials should be protectively coated. Subsurface improvements should be backfilled with graded rock to provide a gas vent to separate the outside face of the substructure and the active material by a minimum of 18 inches.

Access manholes in sanitary sewer lines will provide a means for monitoring the line profile. Covered sanitary sewer lines less than 18 inches in diameter are difficult to examine at the standard manhole spacing of 300 feet. Detection of problems due to settlement will be facilitated if manholes are placed at a maximum distance of 200 feet. Drop manholes should have easily removable plugs to facilitate visual inspection.

Natural gas mains should be provided with valves near and exterior to the interface if automatic shutoff instrumentation has not been provided. Individual gas services should be provided with shutoff valves next to the mains.

MAINTENANCE

Maintenance requirements on sanitary landfills should be stringent. Gas control devices or safeguards should be maintained at all times in good working order. The occupancy or service requirement of any improvement should be maintained functionally and aesthetically. Enforcement of aesthetic provisions is not practicable but the correction of functional and sanitary deficiencies can be made by legal regulations.

Detection of incipient structural deficiency in an architectural or structural component is usually visual. Misalignment or disorientation of a doorway or window may be a clue. Upon noticing a deficiency, the connections of the structure should be suspected and reference should be made to the original building plans and design calculations, if any. For this reason the owner of the structure on a sanitary landfill, for his own benefit, should retain a permanent set of plans and calculations. Structures or parts of structures which have tilted may be allowed occupancy if the ratio of allowable stress to working stress is greater than 1.0. If not, they should be repaired prior to further occupancy or use, or condemned. Prior to much reduction of the allowable safety factor it might be feasible to relevel the structure by jacking, grouting, or adjusting previously installed mechanical devices.

Surface improvements should also be maintained in good condition. Changes in slope of ditches and culverts may occur, resulting in excessive silting, scouring, or permitting water to enter the landfill. Damaged improvements intended to transport water should be repaired or replaced to prevent water from entering the landfill.

Subsurface improvements installed within a sanitary landfill will experience a decrease in the structural factor of safety from the original design condition. When the ratio of allowable stress to working stress is less than 1.0, with respect to basic allowable stresses or stains, they should be repaired or replaced. A good maintenance program may be expected to delay critical diminishment of the factor of safety.

CHAPTER IX

SPECIFIC PROPOSALS FOR ADDITIONAL RESEARCH

THREE YEAR PROJECT PROPOSALS

During the first year program, diffusion-dispersion coefficients having practical significance for soils within a narrow range of application were developed at the Engineering-Science Laboratory (Reference 2). Further laboratory study was recommended to identify and evaluate additional parameters, such as surface absorption, grain size distribution, grain size uniformity, porosity, inlet pressure ranges, and pressure gradient characteristics. Results of such study would enable applicable predictions of gas movement through most types of soils.

Leachates contaminate groundwater. Carbon dioxide is believed to pollute groundwater and the results of an early study indicate that such pollution could be of major magnitude (Reference 6). During the first year of the study it was recommended that a sanitary landfill over an aquifer be constructed under controlled conditions, and that full field investigations be carried out in order to define and evaluate all parameters of CO_2 pollution so that such pollution may be quantitatively predicted.

During the first study year two tests of the effectiveness of gas control systems and barriers were recommended. The construction of two small sanitary landfills, one in a gravel pit or a depression surrounded by highly permeable soils, and another in an area of impermeable soils, together with complete gas monitoring, gas barrier, and gas venting systems was proposed.

During the second study year it was proposed to plan, design, and construct an engineered sanitary landfill model with the following objectives:

(1) To monitor actual movement of underground utility lines due to differential settlement;

(2) To observe the effects of movement on the functional ability of the utility lines and to evaluate possibilities for repairs; and

(3) To evaluate the effects of preplanning for acceptable refuse materials, cells, and inert material as it affects utility lines, streets, landfill boundary interfaces, and simulated building locations.

During the second year a request for additional research to study gas movement through porous media was submitted to the U. S. Department of Health, Education, and Welfare, Public Health Service, Solid Waste Program. The objectives were to develop quantifying data on the behavior of gas flow through a variety of porous media to enable prediction and prevention of future trouble areas due to migration of gases.

SECONDARY RESEARCH REQUIREMENTS

Hydrogen Sulfide

Hydrogen sulfide hazard is high for acute exposures and moderate for chronic exposures. It may cause irritation to the eyes at concentrations above 10 parts per million and to the lungs and mucous membranes at levels only moderately above 20 parts per million. Because of the rapid occurrence of olfactory fatigue, its odor is an unreliable indicator of its level of exposure. Death may occur rapidly with exposures above 600 parts per million (Reference 15). Dumping refuse directly into large bodies of deep water such as ponds and quarries often causes biochemical activity of the putrescible component of the refuse. Hydrogen sulfide may be given off during the process of decomposition (Reference 13). Hydrogen sulfide is not ordinarily a problem on dry landfills, however, a similar problem may arise if a sulfate-containing stream of water passes under or through the fill.

The entrance and exit of seawater high in sulfates into tidal marsh fills may lead to a serious problem from the action of sulfates which reduce bacteria and which in turn produce sulfides (Reference 13). The incidence of problems seems to be rare but one incident reported that workmen in a trench being excavated in a sanitary landfill were asphyxiated by hydrogen sulfide in the fill. The hydrogen sulfide was so strong that silver coins in the pockets of the workmen turned black (Reference 1).

Hydrogen sulfide has received less attention than methane production but it could be important to know more about the causes and properties of hydrogen sulfide produced in landfills. Under what conditions is it produced or controlled? What are its diffusion properties through soil? How does it affect groundwater? What is its effect on microbial populations that cause decomposition?

Landfill Additives

The addition of water to a landfill is reported to markedly increase the production of methane and to increase about 20 percent the initial in-place density of refuse (Reference 7). There may be other possibilities that have not been investigated which might include harmless chemicals that would be conducive to hastening decomposition, chemicals that would prevent decomposition, or special types of wastes that would be beneficial to mix with ordinary refuse to accomplish hastening or prevention of decomposition.

Encouragement of the natural ecology might facilitate a hastened decomposition and earlier utilization of the sanitary landfill. Are there microorganisms that could be planted to augment natural decomposition? Are there strains of safe microorganisms that would increase or decrease gas production? Would it be possible to distribute such microorganisms within a landfill? Would it be possible to find such life forms among natural mold, fungi, safe viruses, or other forms that would not ordinarily occur in a landfill but could thrive and hasten decomposition? Would this be advisable?

Integral Landfill and Gas Control Design

Landfill design for the control of gases and the earliest utilization of the landfill may be a function of cell arrangements within the landfills, barrier materials and application techniques, and the gas control system. Alternative cell arrangement designs could include compact soil barriers, and plastic-type sheeting. One that has not yet been investigated is a semiliquid that could be injected into the soil.

Gases formed in a landfill apparently will escape in spite of all preventative action. The choice of location of vents during the construction of a landfill will facilitate the release of gases in a preplanned location. These combinations of alternatives would include vertical wells, horizontal permeable blankets, horizontal header pipes, vertical permeable blankets, horizontal and vertical impermeable barriers, and burnoff devices.

CURRENT STATUS OF PROPOSED RESEARCH

A review of the data compiled and the experience gained during the project has lead to cognizance of the need to satisfy the following objectives:

(1) Alleviate potential hazards from gases adjacent to existing landfills in Los Angeles County;

(2) Establish engineering data bases for design of gas movement control devices;

(3) Implement Los Angeles County scientific and engineering capability;

(4) Evaluate behavior characteristics of improvements on engineered sanitary landfills; and

(5) Implement regional technical data dissemination and legal control.

These objectives can be attained by continuous efforts of Los Angeles County, Department of County Engineer, selected consultants, and regional representatives of public and private agencies involved with landfilling.

CHAPTER X

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

Chapter I - Introduction

The County of Los Angeles, State of California, in order to formulate construction criteria for sanitary landfills and improvements which would lead to optimum land development and use, has conducted a three-year program of investigation and demonstration into the problems associated with solid waste disposal by sanitary landfilling. Landfilling of municipal refuse is expected to continue for many years to be the principal means of disposal in many areas of the United States. Community development over the years has surrounded and encroached upon many completed landfills resulting in unattractive, potentially hazardous areas within some populated areas. During the study, Los Angeles County, Department of County Engineer, and Engineering-Science, Inc. have been engaged in the study of the subjects of gas movement, groundwater pollution, fire hazard, construction of landfills, maintenance of completed landfills, and construction on and adjacent to completed landfills.

Landfill control within highly populated areas has two facets: (1) existing and completed landfills built without close regard for gas and leachate movements; and (2) prospective landfills for which control devices and procedures can become part of the process of operating and constructing a sanitary landfill. Major factors affecting the integrity of improvements on top of, within, and adjacent to sanitary landfills are gas movement and settlement of the fill. These factors are interrelated because both are influenced by the amount of the decomposition of the refuse. The objectives of the study were to:

(1) Alleviate or eliminate existing problems of adjacent property owners because of proximity to existing sanitary landfills; and

(2) Establish a basis for regulating the various facets related to sanitary landfilling.

The objectives were met through the performance of the following tasks:

(1) The study of the existing state-of-the-art in sanitary landfill construction and operation;

(2) An evaluation of gas movement in certain existing sites;

(3) Review of literature regarding possible effects of sanitary landfills on groundwater quality;

(4) Laboratory experiments for testing flow rate of gas through various soils;

(5) Development of solutions for controlling gases generated in sanitary landfills;

(6) In-situ gas sampling and settlement surveying;

(7) Collection of pertinent information on subsidence, odors, and nuisances in existing sanitary landfills;

(8) Evaluation of the uses of completed sanitary landfills in terms of the conditions of surface and subsurface structures, vegetative growth, and prevalence of odors and nuisance;

(9) Correlation of subsidence to the method of construction and composition of sanitary landfills and the stage of decomposition of refuse materials;

(10) Development of solutions to odor and nuisance problems in completed sanitary landfills;

(11) Evaluation of materials and methods of safe construction of:

    (a) Surface structures on or near sanitary landfills, and
    (b) Subsurface structures in sanitary landfills;

(12) Review and evaluate the scope of existing ordinances, codes, and regulations throughout the United States for control of sanitary landfills;

(13) Formulate criteria for the design and construction of sanitary landfills;

(14) Formulate criteria for inspection, control, and maintenance of sanitary landfills;

(15) Formulate criteria for the uses of lands on and adjacent to sanitary landfills;

(16) Formulate criteria for the design and construction of structures on, and substructures in, sanitary landfills; and

(17) Prepare "Sanitary Landfill Standard Specifications for Good Practice."

During the first year of this study, 1967, local sanitary landfills were inventoried, examined, and evaluated. The extent of migration of refuse produced gases in local sanitary landfills was measured; the geometry of existing sanitary landfills was investigated; the properties of the soil affecting gas movements were identified; gas control devices at existing landfills were designed; and gas and subsidence monitoring controls were installed at strategic locations on existing landfills.

Various types of gas barriers and control devices to retard subsurface gas migration were evaluated. The excavation of a cutoff trench backfilled with highly permeable gravel and rock proved to be an effective method for control of gas movement. Two other gas control systems were developed. One of these systems consisted of five wells located about 100 feet from the completed landfill. Each well was excavated to the equivalent depth of the refuse and operated on the basis of combined gas suction and air flushing. Another control system consisted of an asphalt-type membrane installed under a greenhouse constructed directly upon a fill. This barrier was designed to prevent gases from moving through the fill cover into the confinement of the greenhouse. Gas monitoring indicated all systems were effective.

Subsidence of monuments and survey points that were established at six selected sites during the first year of the project study was measured throughout the study period. The resulting data were examined for correlation between subsidence and other construction parameters. A laboratory experiment for investigating subsidence characteristics was correlated with the field data. Formulae were developed for predicting ultimate subsidence of completed sanitary landfill surfaces under a range of specific material and moisture controls.

Groundwater quality degradation was studied and analyzed. A detailed study of leachate production characteristics as a function of the stage of decomposition of typical refuse materials was conducted in the laboratory. A leachate pollution index was developed based on total dissolved solids to determine the quantity of solutes leachable from refuse fills.

Available information on landfills throughout the United States, was obtained by mailed questionnaires, visits to completed sanitary landfills, and interviews with selected experts. All data were collated for the development of criteria for materials and methods for safe construction of surface structures, surface improvements, and subsurface improvements on, in, or adjacent to the sanitary landfills. Previous recommendations were reviewed and reevaluated on the basis of latest information and analyzed for means of implementation.

"Standard Specifications for Good Practice" were developed into two sections providing for administration and regulation of planning, design, construction, and maintenance of: (1) sanitary landfills; and (2) improvements on, in, and adjacent to sanitary landfills.

Chapter II - Monitoring Landfill Subsidence and Laboratory Development of Subsidence Predictions

Surface subsidence, differential settlement and lateral surface displacement were monitored at certain completed landfills. Settlement records were maintained, plotted, and selectively analyzed.

Subsidence rates at Site 5 were larger during earlier observations and during the 1968-1969 rainy season. At Site 11, subsidence curves showed no significant slope changes. Cumulative settlement appears to be independent of fill depth in this case, but apparently it is a function of the water content.

The number of landfills observed did not represent an adequate statistical sampling, but the program was useful in determining the reliability of future correlations. Lack of material control will hinder accuracy of any predictive methodology except in unusual cases. One such case showed two monuments on Site 5 settling in a manner that could result in an asymptotic extrapolation that could represent a field prediction of ultimate subsidence for the landfill beneath the two monuments (Figure II-1).

Future full-scale field test data should include: (1) measurement of subsidence at various depths within the fill; (2) indices of compaction, moisture content, and homogeneity; and (3) instrumentation to measure the response to seismic disturbance.

Laboratory studies, on the other hand, may more viably reflect stochastic sampling conditions. To date, the technology available for predicting subsidence and compaction of landfills is comprised almost totally of empirical procedures. The fundamental mechanisms active in sanitary landfill subsidence predictor equations require observation of the effects of varying generic factors such as initial compaction, compaction due to overburden, and biodegradation of organic fill components.

Required preparatory activities include: (1) identifying physical, chemical, and biological phenomena of decomposing refuse; (2) defining analogous principles of soil mechanics; (3) evaluating landfill experience; (4) generating a laboratory program; and (5) establishing and documenting the predictive relationships.

The general components of landfills include garbage, fibrous organics, metal, old tires, glass, objects of varying biodegradability and density, demolition wastes, and ashes. Biodegradation may be generally defined as the process whereby organic material is metabolized by microorganisms. In a landfill essential nutrients for biodegradation are usually present.

The primary premise of this study was that the mechanisms explaining the action of consolidating soils and of organic matter undergoing biological decomposition provide a basis for developing relationships to describe the behavior of landfills under controlled conditions and for deriving rational relationships describing these phenomena.

The laboratory program was divided into successive efforts dealing with compaction and with decomposition as separate and sequential unit processes. Stock mixtures of nine varied compositions were subjected to initial compaction analogous to conditions at a landfill.

The composition of the components was classified and documented. Two sets of refuse compaction experiments were conducted, one set to establish maximum densities and minimum porosities and one set to simulate the compaction by earthmoving equipment at a landfill. The compacted cells were allowed to decompose and subside in a constant temperature room for 193 days. Records were kept of weight, temperature, and subsidence. At seven months time, confined compression tests were made. The refuse compaction tests were then conducted.

Observations were made on the time variation of weight loss and subsidence. Unit weight changes were then calculated and analyzed as a function of its parameters for selected paper contents, water contents, and refuse texture. Average annual subsidence rates for all cells were established and analyzed.

Subsidence observations at the end of the study period were pictorialized and analyzed (Figures II-31 to II-35). Formula II-2 was then developed by fitting an interpolated consolidation curve between the boundary indices.

$$C = k_1 \ln (t/t_o) \qquad \text{(II-2)}$$

where: C = compaction
k_1 = slope of each time-deformation curve
t_o = 0.1 minute
t = time, minutes

Stress-strain data were developed and used to: (1) evaluate the factors affecting initial compaction, and (2) correlate unit weight, voids ratio, and initial compaction (Figure II-45). Initial compaction was then formulated as:

$$C_i = 100 \frac{\gamma_f - \gamma_i}{\gamma_i} \qquad \text{(II-3)}$$

where: C_i = initial compaction, percent
γ_f = final unit weight, lb/cu ft
γ_i = initial unit weight, lb/cu ft

Secondary compaction, the strain occurring subsequent to initial compaction, is assumed to be independent of initial compaction. Equation II-4 was formulated by normalizing the strain scales to enable expression of secondary compaction as a percent of full sample height independent of initial compaction.

$$C_s = k_s \ln (p/p_o) \qquad \text{(II-4)}$$

where: C_s = secondary compaction, percent

k_s = secondary compaction constant, units of percent

p = stress, lb/sq ft

p_o = base stress (1,260 lb/sq ft in this study)

A landfill can be described as a multilayer amalgam of individual layers of decomposable compactable material, each layer with a specific history of overburden and each with a specific age. Decomposition is transient in character, and settlement related to it is rapid in early stages. It may be assumed to reach an early maximum rate. For a maximum at one-half year and rate changes at one-half year and one year, terminating at two years, the following may be used to estimate subsidence due to decomposition:

$$S_D = \hat{k}\int_0^{0.5} 2t\,dt + \hat{k}\int_{0.5}^{1.0}(1.9-1.8t)\,dt + \hat{k}\int_1^{2} (0.2-0.1t)\,dt \qquad \text{(II-5)}$$

which is integrated over the 2-year period to:

$$S_D = 0.575\,\hat{k} \qquad \text{(II-6)}$$

where: S_D = settlement due to decomposition, percent

$\hat{k}$ = average annual subsidence rate observed after 180 days of decomposition, percent per year

The settlement of a specific lift in a fill by each of the three mechanisms studied in the laboratory is described by the following aggregated statement:

$$S_L = 100\left[1- (1-0.01\,S_D)\,(1-0.01\,C_i)\,(1-0.01\,C_s)\right] \qquad \text{(II-7)}$$

where: S_L = settlement in a lift, percent

S_D = settlement due to decomposition, percent

C_i = initial compaction, percent

C_s = secondary compaction, percent

Which, when reformulated for a number of lifts, then summarizes subsidence over a multilift landfill as:

$$S_{F_t} = \frac{\sum_{t_i, p_i} S_{L_i} H_i}{\sum^{n} H_i} \qquad \text{(II-8)}$$

where: S_{F_t} = the settlement of the total fill due to decomposition, initial compaction, and secondary compaction at time t, percent of total fill height

S_{L_i} = settlement which has occurred in lift i over time t_i and pressure p_i, percent of lift height

t_i = age of lift in fill at time t

p_i = compaction stress on lift i at time t

H_i = initial emplacement height of lift i

Chapter III - Gas Movement and Control

Inside sanitary landfills, biological decomposition of organic matter takes place resulting in the production of gases. These gases, primarily methane and carbon dioxide, may create problems which restrict beneficial use for completed landfills by contributing to potential fire hazards, and causing impairment of groundwater quality.

The basic objectives of the study included: (1) the analysis and evaluation of the directions and extent of the gas movement; (2) the correlation between the direction and extent of gas movement and the surrounding soil characteristics; (3) the performance of laboratory experiments for testing the effectiveness of various natural soils in reducing movement of gases from sanitary landfills; and (4) the development of practical methods for controlling the movement of gases.

Ten completed sanitary landfill sites were considered for conducting detailed gas movement studies. A soil sampling program was executed to obtain a knowledge of the nature of the soil material adjacent to the fills. Indigenous soils were analyzed for determination of grain size distribution, soil classification, specific gravity, dry density, and moisture content. In-place density of the soils was measured.

A monitoring program of gas concentrations adjacent to selected landfills was instituted. Gas probes were installed and samples were collected and analyzed in percent by volume for carbon dioxide, oxygen, nitrogen, methane, and in some cases hydrogen sulfide. The extent of the gas movement, primarily methane, from each landfill was demonstrated where possible by plotting contours of equal concentration.

At Site 1 a gas control system was installed. Testing indicated that the gas concentrations in a parking lot across the street from the fill were reduced. Site 2 produced carbon dioxide and methane in quantities not consistently measurable. Site 3 was monitored early during the study. Limited gas production was observed. Analyses of the samples taken adjacent to the filled areas indicated no significant migration of methane and carbon dioxide. At Site 5 sampling of gases from probes installed in and on both sides of the barrier gravel trench, constructed prior to this study, showed that the trench is venting gases and inhibiting movement of gases across the plane of the trench. At Site 6 an irregular pattern of subsurface gas movement was detected. Movement of gases to the north of Site 6 was indicated when methane surfacing through a crack in the floor of an industrial building was accidentally ignited. Further investigation detected intermittently located areas of high concentration levels. At Site 7 no particular pattern of lateral gas movement could be established. At Site 8 plots of methane concentration contours indicated a slight decrease in the extent of lateral gas movement into adjacent areas. At Site 9 gas analyses of samples continued to indicate extensive movement of gases and high methane concentrations. A gas control system was constructed by the local governmental agency. There was no indication that gas movement into an adjacent residential area was being reduced. However, recent grading operations have now exposed three sides of the landfill to the atmosphere, and it is expected that gases from the fill will begin to pass from the exposed sides with the resulting reduction in gas movement to the residential area. At

Site 10 continued work on the site precluded taking more than two sets of samples. Traces of hydrogen sulfide were found, indicating the possible existence of salt water intrusion in the fill from the adjacent bay.

Laboratory experiments were conducted on various natural soils to determine the gas permeability characteristics under a range of moisture content and the gas pressure conditions. The objective was to study the suitability of various soils for gas barrier membranes. Coefficients were calculated based on an analytical solution of a fundamental differential equation governing the flow of gases through porous media and utilizing methane concentration history curves derived from each experiment (Reference 2). The results of these experiments indicate that the rate of movement of methane by diffusion-dispersion is slower through soils with fine particles than those with coarser particles, for both air-dry and optimum moisture conditions and under all conditions of inflow gas pressure. Molecular and dispersive components of the calculated coefficients were not distinguished. However, the high convective movement of gases in coarse grained soils is undoubtedly responsible for the high diffusion-dispersion coefficients of methane in these soils. The convective flow component of gas migration may be significant for the case of highly permeable media such as the sand and gravel, whereas it will be rather insignificant for fine soils and when subject to small pressure gradients. The coefficient of gas permeability of the various media was not determined; however, when a fine soil is compacted under optimum moisture conditions to 90 percent or more of the maximum density, the gas permeability of the medium will be so small that the flow by pressure gradient will be reduced to inappreciable amounts. The results substantiated the presumption that fine textured soils, such as sandy clay, silty clay, or clay, form an effective barrier to gas movement even at low moisture content. When compacted at optimum moisture content these soils prevent any appreciable flow of methane or other gases under differential pressures of one or more atmospheres.

Fires and explosions have resulted from the accumulation of methane gas in confined spaces on or adjacent to landfills after the gas became trapped and concentrations reached flammable levels. Measures which have been taken to prevent the movement of gases into adjacent soils include barrier and ventilation devices.

During this study, three gas control devices were designed and constructed at existing completed sites where the gas movement monitoring program indicated extensive migration of methane gas into adjacent soils or through the fill cover. At Site 1 a device was constructed consisting of five wells, each 30 inches in diameter and 60 feet deep, spaced at approximately 40-foot intervals. Each well was divided into three sections, filled with gravel, and topped with concrete. Three six-inch pipes are installed in each well and connected to a 12-inch header pipe by a six-inch flexible, reinforced, neoprene hose, which is connected to the suction side of a 25 horsepower blower. Gas that is entering each six-inch pipe may be vented directly to the atmosphere or pumped.

At Site 5 an asphalt type membrane was installed beneath the floor of a greenhouse. The membrane consisted of a multiple layer, fiber reinforced, asphalt laminate fabricated in place. This was constructed over a four-inch layer of gravel in which were placed two three-inch perforated pipes, one at each end of the area, to vent the gravel layer and prevent excessive buildup of gas concentration beneath the membrane. A layer of pea gravel was placed on top of the liner to form the floor of the greenhouse. Sampling probes were placed to test the effectiveness of the device.

At Site 8, privately owned, a gas control system consisting of a trench, two wells, and a burnoff device was installed. The trench was located between the refuse fill and the property line near the interface in the area of the greatest movement of gases. Two wells were located 200 feet apart in the center of the area where the methane concentration levels appeared to be the greatest. Surface drainage was provided. The two wells were drilled directly below the trench and filled with gravel. Each well is 24 inches in diameter and 50 feet deep. The wells and trench are fitted with pipes and headers and vents directly to the burner. A cap, perforated with several 1/8-inch diameter orifices, was installed on the pipe to prevent the flashback of any flame down the pipe. Turnoff valves are provided between the trench pipe and the well pipes. The trench was filled with gravel and capped with a layer of concrete to prevent water from entering the trench and the gas and odors from exhausting through the trench. One four-inch perforated pipe was placed in each well, extending to the surface and capped to provide venting for future experimental purposes. In the future, monitoring of existing and newly installed probes will allow a determination of the effectiveness of this control system and provide information of the arrangement of vent pipes under which the system will be most effective in intercepting the flow of gases beyond the device.

During the latter stages of the study, detailed testing and monitoring was performed in order to examine the relative effectiveness of the control devices in reducing or stopping gas migration. At Site 1, experimentation was developed to identify the optimal sequence and duration of pumping for one or more of the five wells. Initial testing indicated that the system is capable of effectively preventing the flow of methane into the area immediately across from the line of wells and that complete removal of methane in the soil atmosphere could be achieved. Continued testing to develop the maximum spacing of wells which would prevent gas movement and the minimum rate of pumping necessary for adequate control was attempted during the third year. Simple venting without pumping produced no significant change and did not impede the flow of gas. It was determined that pumping from just one pipe in the center well created an influence across the plane of all the wells. Further testing indicated that continuous forced ventilation from just one well would provide a satisfactory gas migration barrier to a distance of from 150 to 200 feet. It was concluded that adequate stoppage of gas movement into the area across from the well plane could be achieved by pumping 315 cfm continuously from one pipe and one well. Subsequent tests confirmed that spacing of wells with similar suction characteristics could be approximately 150 to 200 feet apart and be effective for areas with similar soil characteristics as Site 1.

The testing program at Site 5, the greenhouse, consisted of periodically sampling gases in the probes to monitor the effects of the barrier on the concentration levels of the methane beneath, above, and adjacent to the floor of the greenhouse. Monitoring was performed four times during 1969. This device appeared to effectively prevent methane flow from entering the interior of the building. Tests were also conducted to determine whether or not the gravel filled trench was still effective as a barrier. Analyses of gases taken from probes adjacent to the trench showed that the trench was generally still acting as a good barrier.

At Site 8, the privately owned site, the construction of the control device was not completed until late in 1969, the third and final year of this study. Gas emerging from the vent pipe was ignited on the day of completion. The system was not in operation long enough to fully evaluate its effectiveness; however, early evaluation of the results derived from the probe sampling indicated that ventilating with one vent pipe was insufficient to reduce the flow of gas into the adjacent area.

Part of a training course conducted by Pacific Telephone Company is a demonstration of the characteristics of toxic and flammable gases. The Training Division uses a model manhole, consisting of a forced ventilation blower, a control box, and appurtenances to supply, regulate, and explode prepared gases simulating natural gas.

A similar apparatus was designed and built to investigate the explosive characteristics of gases on selected research sites. The unit consisted of two separate boxes: one simulating a confined space such as a substructure or under-floor area of a building; the other, a control unit containing a source of power, connected to the box in which the explosions occur. Methane concentrations were tested near the bottom, the center, and top of the explosion box and recorded. Detonation may be induced at any selected level at tested concentrations. The explosion unit was field tested on landfill gas. Methane concentrations were sampled. Concentrations ranging between five and seven percent were read prior to explosions. Concentrations of less than five percent did not explode. In some instances explosive concentrations were rapidly reached within minutes after previous explosions had resulted in complete evacuation of gases from the explosion box. A log, consisting of two sheets, was kept to provide the necessary information regarding sites and site characteristics, soil characteristics, weather, insulation data, detonation data, etc. Other pertinent and necessary information was then developed and used for further testing. The use of this apparatus demonstrates a transition between the theory of landfill gas flammability and potential enforcement of any future Sanitary Landfill Ordinance.

Chapter IV - Groundwater Pollution

Analyses of waters which have been in contact with solid wastes have shown that both chemical and biological pollutants may be present. The liquids that result when water comes into contact with refuse either by percolation or immersion are generally termed leachates. A fill may be in contact with groundwater or surface water resulting in direct leaching through the fill material; or water originating in another location may drain through the fill. Groundwater in the immediate vicinity of a disposal site may become polluted and unsuitable for domestic and/or irrigation use if the solid wastes intercept the zone of saturation and come into contact with the groundwater or if the leachate reaches the groundwater. The velocity of water through the material is dependent upon the permeability.

Indices of groundwater pollution were determined in laboratory experiments during this study. Leachates were analyzed for total dissolved solids, chemical oxygen demand, hardness, alkalinity, pH, organic and ammonia nitrogen, fluorides, sulfates, and nitrates.

The major gases normally produced within a sanitary landfill are carbon dioxide and methane. Since methane is relatively insoluble in water and lighter than air, it is not expected to contribute materially to groundwater pollution. Carbon dioxide gas is heavier than air and highly soluble in water and may contribute to increased mineralization in groundwater. However, water that has been impaired by carbon dioxide will be diluted within the groundwater body.

During the leachate experiments samples from two sanitary landfills, Site 1 and Site 12, were tested. Two synthetic sample series were prepared. All samples were leached simultaneously under the same procedures to provide comparisons. The results of the experiment define a correlation between chemical oxygen demand and total dissolved solids in the field samples and in the synthetic refuse. A Leachate Pollution Index was proposed based on total dissolved solids.

Site 8 was a known source of carbon dioxide and methane. Site 8 was originally thought to have been placed five above above anticipated high groundwater. Borings later determined that Site 8 waste material was, in fact, below groundwater. An earlier investigation based on the first assumption concluded that the impairment of well water quality 400 feet from the site was primarily due to a solution of carbon dioxide gas and that the major source of carbon dioxide in the vicinity of the well was decomposing refuse in the Site 8 landfill. This conclusion was a significant factor in decisions by regulatory agencies to inhibit the installation of new filling operations in areas with similar geologic strata. Since it was later found that the waste material was placed below high groundwater, additional information concerning water degradation by gases is needed.

Chapter V - Criteria for the Location, Design, and the Construction of Sanitary Landfills

The selection of a location for a sanitary landfill should be based on benefit to the community while assuring maximum personal safety and security of property of its neighbors, and a function of the local topography and geology. Under certain circumstances existing depressions in lands, such as old gravel quarries, normally useless gullies, and abandoned strip mines may be suitable for landfill sites. The prime physical considerations of a potential location are the practicality of preventing water pollution and gas migration. To minimize water pollution, sanitary landfills would be most ideally located above native soils of low permeability if over a usable water supply.

Decomposable solid wastes should not be placed in seawater, salt water, or waters with high sulfate content since they may react to form hydrogen sulfide gas. Hydrogen sulfide gas is exceedingly toxic and dangerous to animal life.

General planning should provide for a horizontal separation distance between sanitary landfills and adjacent incompatible land uses to allow for the possibility of explosive gas migration. Engineering and geologic data may not be available at this stage of community planning. A horizontal separation distance of 1,000 feet is recommended for this purpose. Chapter VII gives possible conditions for varying the separation distance.

The means for accomplishing the separation of water and pollutants requires planning for the construction of the landfill. Original construction plans should show the proposed means of controlling the basic types of water intrusion. Periodic maintenance and monitoring may affect the success or failure of pollution defenses. A groundwater monitoring program should be developed at the planning stage and implemented during construction of the landfill.

One means of separating water and pollutants is by requiring a vertical separation distance between the bottom of the landfill and of the high water surface of underlying groundwaters. In soils of low permeability the required vertical separation distance varies from state to state. Until results of testing under controlled conditions yield satisfactory distances, landfills located in permeable soils less than 30 feet above groundwater should be underlain with barriers to lessen the chance of pollution.

Drainage galleries may be required to keep underground waters from flowing across the interface between the landfill and natural soils, where several aquifers separated by impervious soil would be intersected by a proposed landfill. In addition to subsurface controls and setbacks--ditches, piping, and dikes should be used to keep surface waters from flowing across the interface of the landfill and natural soil.

Gases originating within a sanitary landfill which escape directly through the soil cover into the atmosphere are quickly diffused. Gases migrating to confined spaces produce explosion hazards in addition to water pollution. Controls should be a matter of properly directing the gases to harmless points of disposal. The major factors affecting gas production and control are the percentage of organic material, the permeability and thickness of soil cover, temperature variation, and moisture content. Control efforts will also be affected by factors such as the permeability of the soils underlying and adjacent to the landfill and subsidence.

The selection and arrangements of systems of materials and methods for gas control have been classified as: (1) peripheral; (2) central; (3) natural; (4) mechanical; (5) internal; (6) external; and (7) combination. A variety of materials are available for use as barriers but most have not been tested for impermeability, inertness, and endurance. In addition to natural soils these materials include polyvinyl chloride sheeting, neoprene, butyl or synthetic rubber, laminated hot-asphalt-mopped building paper, and others. A gas monitoring program is essential to the proper evaluation of gas production, gas movement, and gas control systems.

Subsidence is a function of consolidation resulting from initial compaction of refuse materials, compaction of refuse materials due to overburden, volume reduction caused by decomposition of the refuse, volume reduction caused by saturation with water, and volume reduction resulting from removal of leachable materials.

Differential settlement may be defined as nonuniform settlement in the area adjacent to a structure or surface improvement due to consolidation of underlying strata caused by dead and live loads and other phenomena (Reference 17). It differs from subsidence in that it is less uniform and is caused by applied forces in addition to overburden of the fill. A major factor which will affect the economic life of a development on a completed sanitary landfill surface is the effectiveness with which a sanitary landfill supports its improvements. This will be a function of the magnitude and timing of its ultimate consolidation and the reliability of predictions which affect cash flow funding for maintenance. Engineering control is, therefore, imperative during the construction of the landfill if a usable and dependable surface is to result.

The condition of the finished surface of the landfill is also dependent upon conditions at each finished surface at the top of each lift within the landfill. If compaction of the intermediate lifts is not maximized, this will have an effect on the ultimate use of the landfill. Where adequate material is available, one foot is recommended as the compacted thickness for the daily cover. The minimum final cover for the entire landfill is recommended to be three feet. In no case should any permanent excavation be made to reduce the cover to less than three feet.

The major purposes of the daily earth cover are to control noxious odors, inhibit access of pests and vectors, and improve the appearance of the landfill. The cover should be free from putrescible matter or large objects, be well compacted, and not subject to excessive cracking or erosion. The cells also provide a degree of fire protection.

Maximized initial compaction coupled with minimized heterogeneity should result in the earliest ultimate consolidation. Surcharge loading applied to sanitary landfills will accelerate earlier consolidation. Volume reduction caused by biological decomposition may be expected to result from wetting of the refuse. The addition of water, to an appropriate moisture content, for refuse material and cover material may be expected to provide the earliest ultimate consolidation. However, the addition of water to a sanitary landfill should be carefully controlled. Excess water in the interstices may be avoided by providing for drainage over finished cells and installation of surface and subsurface drainage facilities.

Side slopes should be designed to minimize potential sloughing. A desirable average side slope should be 3 (horizontal) to 1 (vertical). This average side slope includes required benching and interceptors. Under certain conditions sloughing should be anticipated and slough protection should be required. Slough protection may be provided by the placement of inert embankment or cutoff walls.

Monitoring of the vertical movement of the individual level of daily cover could be of benefit to eventual determination of the utility of the site. Topographic control within a few tenths of a foot, after each lift operation, would facilitate monitoring; or, risers could be installed during construction of the landfill and extended to the completed surface for subsidence monitoring surveys. Close vertical survey controls should be provided for the subsidence monument system.

Materials should be selectively classified and placed in predefined sanitary landfill site locations. Each site should receive two classifications, a location classification and a materials classification. The location classification is based on the unmodified and unprotected geology and configuration of the site. A site having received its location classification may, with the installation of suitable protection, receive a materials classification of greater groundwater hazard than the unmodified location classification and consequently would accept all materials of greater or lesser hazard than the materials classification.

Uniformity of settlement requires a limit on the size of acceptable materials. However, exceptions should be provided for portions of landfills planned to be utilized only as green space or in deep canyon landfills. Bulky, heavy materials, such as concrete or bricks or large diameter logs should be placed at the bottom of the fill and not in the top or sides where they may provide an unwanted surcharge effect, create increased heterogeneity, and provide rodent harborage.

In deeper landfills the overburden will contribute to consolidation of the materials placed near the bottom. Although the extent of this consolidation is variable, some adjustment of the active material lift heights would be appropriate. Therefore, the following table was developed on this premise using maximum lift height as a function of the remaining fill depth or height. For depths of 0 to 20 feet to the bottom of the final cover, a lift height of more than three feet would create an inordinately large proportion of active material to inert material. From the following table, for a maximum lift height (h), for each remaining fill depth or height (H), it may be observed that the ratio of active material to inert material (based on one foot intermediate cover between lifts) varies from 3 to 1 in the shallowest landfill to 20 to 1 in the deepest landfill. The least percentage of lift height to remaining fill height varies uniformly from 15 percent in the shallowest landfill to five percent in the deeper landfills. The following maximum allowable lift depths should be considered:

H (feet)	h (feet)	Minimum Percent (h/H)
0-20.0	3	15
20.1-50.0	4	8
50.1-75.0	6	8
75.1-100.0	8	8
100.1-200.0	10	5
200.1-300.0	15	5
deeper than 300.0	20	5 (if H = 400)

Daily cover should be in place and compacted by the end of each working day. The daily cover should be placed to form a completely enclosed cell. The final cover should be in place and compacted within not more than 120 days after the final daily cover and prior to a rainy period. During periods of precipitation, cover should be applied as rapidly as possible. Two percent should be the minimum final slope. Four percent is recommended as a maximum, where possible.

Finished landfill surfaces require drainage protection. Terrace drainage should be provided with slopes adequate to drain as subsidence occurs. The slopes should be designed for the tributary drainage area and a flow of not less than 4 feet per second nor more than 8 feet per second. All finished slopes should be planted and irrigated to promote the growth of ground cover. Planting requirements vary for differences in side slope. The most dependable water system is considered to be the sprinkler system, but this is not always practical. In some cases hand watering may be adequate.

A responsible representative of the landfill operator should be available at all times. A daily log of all operations should be maintained and include the quantities and types of refuse accepted each day, placement and lift heights, unusual occurrences, the numbers and responsibilities of employees on the job, and the type and use of equipment used on the site. Precautions should be instituted to prevent fire. Communication between the employees and site office and the local fire department should be provided in addition to standard safety equipment.

Reclamation and reprocessing operations (away from the sanitary landfill site) should be encouraged to enhance the economic desirability of landfilling. Metals, papers, fiberboards, rags, and glass have variable economic values in different locations. The removal of reclaimable items will tend to diminish heterogeneity.

All weather, dust free access roads, turnaround space, clearly marked directional signs, and no smoking signs should be provided. Clean sanitary toilet facilities and a first aid kit should be provided on the premises for all employees. Operations which extend beyond daylight hours should be provided with night lights. Common shelter and heating should be provided as necessary.

Chapter VI - Criteria for the Inspection, Supervision, and Maintenance of Sanitary Landfills

Inspection by a qualified deputy of the local governmental agency is necessary to determine the effects of the completed work upon the plan objectives and the likelihood of danger or inconvenience to any person or property. During the course of any construction project, various interpretations may be placed upon the plans and specifications. Appropriate remedy should be available. Sanitary landfill operations should be inspected as often as necessary to accomplish regulatory objectives; however, continuous inspection by a public agency is uneconomical and may be avoided.

Structures on and adjacent to a sanitary landfill should be inspected to assure compliance with legal regulations. Surface improvements on a sanitary landfill and the subsurface improvements in or adjacent to a sanitary landfill should be inspected as often as necessary during and after construction. Access to structures, surface improvements, and subsurface improvements should always be available.

All construction activities on a landfill site should be continuously supervised by a responsible representative of the operator, the constructor, or a subcontractor. If none are available, an inspector certified by an officer of the local governmental agency should be provided.

Special conditions may require that reports be submitted. These should be certified by the supervisor responsible for the particular work item. Structures designed under special provisions of the applicable local building code may require continuous supervision due to special conditions. It is possible that the administrative officer and the chief building official may have bilateral responsibilities for construction on sanitary landfill surfaces. If so, the architect or engineer responsible for such design should provide written certification to the administrative officer that each structure or portion thereof requiring continuous supervision was constructed in conformity with the approved design and applicable regulation. The designer of surface improvements and subsurface improvements may be either a civil engineer, mechanical engineer, or an electrical engineer, who should certify in writing that the construction is in conformity with the approved design and applicable regulations.

The final cover on a landfill may be expected to subside and crack, thus impairing drainage slopes and possibly resulting in ponding. Filling and scraping of the affected surfaces will be necessary to alleviate or prevent ponding and maintain the integrity of the cover. Ground cover vegetation should be required to stabilize the surface. The effects of erosion on ground cover vegetation may be minimized by replanting similar or more stable species. Maintenance of monitoring devices may be facilitated by well kept records. The integrity of each gas control device should be maintained. Patching of membranes may be required and feasible in some instances. Gas vents may be infiltrated by materials reducing cross sectional area. Corrective measures may require flushing out with water or blowing out with compressed air. Monitoring and analysis of gas concentrations should be required until gas production declines to a safe level and remains safe over a measured period of time. Control of odors may occasionally be required. Regular periodic inspections should be made for signs of rodents and winged pests and appropriate steps taken as necessary.

Chapter VII - Criteria for the Uses of Land On and Adjacent to Sanitary Landfills

The uses of all the lands should remain principally a function of the general plan of each individual community which should recognize that landfilling and its associated phenomena should be considered. The best possible completed landfill surface can not be expected to provide the stability required for heavy structural and traffic loadings; however, properly planned, completed landfills in the future may be used for heavier loadings if planned and engineered for them.

A general plan may be importantly affected by a correlation between the recreation plan and the solid waste plan. The street and highway plan is a component of the general plan that could remain unaffected by the reuse of the sanitary landfill, if the landfill is planned to comply with the street and highway plan by providing for central rights-of-way as part of the landfill construction.

The surfaces of existing or completed landfills, upon which there is no prospect for successful development requiring extensive improvements, should be controlled by statute law to facilitate compatible uses.

which may include park and recreational use, open assembly area, temporary heliports, or other uses with minimal or no improvements.

Some existing completed landfills may have been planned and constructed to minimize the problems due to settlement and subsidence. Such landfills may be acceptable for planned use if they can be provided with suitable gas controls. They should be subject to applicable engineering and governmental regulations and should not be used for any purpose not allowed on proposed landfills. Future sanitary landfills may be engineered and constructed to be suitable for a variety of uses. If the landfill is planned to minimize subsidence effects by reserving inert strips and areas and by increasing the ratio of earth to active material, loadings from traffic and building uses will be more acceptable.

A gas monitoring and analysis program is the best practical means of determining the existence and extent of hazards from gases. If gas concentration histories and refuse core sample analyses indicate a long-term decrease in methane production potential, construction of enclosed occupancies without gas control systems may be permissible, unless hydrogen sulfide is present.

Where there is the remotest possibility that gases may migrate to and concentrate in confined areas or rooms, human use should be prohibited. Closed habitable construction on adjoining undeveloped and uninhabited lands should be subject to a minimum separation distance of 1,000 feet, if engineering and geologic data is not available to indicate otherwise.

Under controlled conditions the selection of a location for a landfill may be a function of adjacent existing uses. An indefinite number of uses encroach upon lands adjacent to existing dumps and sanitary landfills. The degree of safety can be determined by monitoring gas concentrations. Residents of land adjoining existing landfills should be made aware of the potential hazards, if any, and of the degree of hazard, if determinable.

Chapter VIII - Criteria for the Development, Construction, and Maintenance of Improvements On, In, and Adjacent to Sanitary Landfills

The use of each completed landfill site should be planned on the basis of specific merit. Although construction on sanitary landfilling is not generally advocated, the following construction techniques and precautionary measures are offered. They are not intended to be complete solutions to landfill problems, but are presented to provide a basis upon which further specialized engineering thinking can be applied.

Gases may be prevented from entering improvements by utilizing gas control barriers and vents of proper material. Acceptable alternatives for barrier materials include: vinyls, copolymers, terpolymers, building paper, and water stop materials. Gas vents may be required around the periphery of a structure, in plumbing access spaces, and electrical panels. The gas control system around a building may be comprised of trenches filled with granular material, perforated pipe drains, combination vent stacks, and foundation drains. Utility entries should be protected to prevent gases from following permeable trench bedding and venting into confined spaces. Collars and connectors to seal off gases may be fabricated.

The most pronounced differential settlement generally will occur under buildings founded partially on inert material and partially on sanitary landfills. Under buildings located totally on a sanitary landfill, prediction of the locations at which differential settlement will occur is more complex. It should be anticipated that this might locate anywhere under a foundation wall. The magnitudes, locations, and directions of additional stresses, due to resulting distortions, should be predicted and resisted. Proper structural design should include the assessment of all potential loading. Safety factors should be conservative and analyses intensified. The primary structural components which will be affected are slabs, piling, raft foundations, walls, and the total structure concept which includes connections. Piling should be designed for all vertical and horizontal loading, the down drag effects of frictional resistance to subsidence and settlement, and any floor loads transmitted directly to the fill adjacent to piling. Raft foundations upon which the total stability of the structure is dependent are less desirable than piling foundations, but may be permissible. Spread footings and pads should not be permitted to rotate. Rotation can be inhibited by monolithical struts. Under select span and width conditions it would be advantageous to utilize rigid building walls as deep girder foundation elements.

Surface improvements are more likely to be damaged by the effects of differential settlement or subsidence. Surface channels, ditches, and drains that might settle unevenly will have their hydraulic characteristics impaired. Design alternatives include either design for the conditions accruing from subsidence or differential settlement or design to prevent differential settlement. In the first instance, flow lines may be designed at the steepest subcritical slope. Subsequent flattening of the grade might result in uneven deposition of solids but need not impair the overall function of the drain. It should be recognized in the design that slopes may become supercritical; therefore, freeboard should be provided. Drainage channels which are provided with overlapping sections may be undercut by eddying currents. At the points of overlap, subsurface cutoffs or checks should be provided at right angles to the flow line and also parallel to the flow line.

When possible streets should be founded on inert material. This can be accomplished by means of preplanning if the cost of building a high inner embankment does not render a landfill operation uneconomical. Streets built on a landfill with an optimized ratio of solid wastes to inert material should be of asphalt concrete, thus flexible and able to sustain light automobile traffic loadings.

The design of concrete curbs, gutters, and sidewalks may be modified to provide horizontal spans with maximized resistance to horizontal and vertical loading. During the data survey phase of this study it was discovered that surface improvements such as utility poles, fences, street signs, and simpler improvements lost their plumb due to subsidence. Utility poles may be set in concrete bases with adjustable anchor bolts and some poles may be releveled by the use of adjustable turnbuckles and cables, but individual ingenuity may also be required in specific design situations.

A building not founded on piles probably will settle more than the surface improvements. A building founded on piles will settle less than surface improvements over landfill cells. In both cases flexible connections should be required between the building and the surface improvement. Subsurface improvements in juxtaposition to surface improvements and structure improvements will be subject to the same peculiarities of gas control.

Particular attention should be directed toward the design of pipe bedding. Granular materials convey gases but may be acceptable if vertical barriers are built into the bedding between manholes, in the form of concrete saddles or cradles. Plain or reinforced concrete bedding is effective for gas control but it imposes an additional load on the supporting landfill.

Subsurface improvements are susceptible to the effects of differential settlement under conditions which are usually difficult to detect. Placing utility lines in an openable trench may be one solution to the inspection problem. The design for underground piping should be conservative.

Monitoring subsidence of underground utility lines can be facilitated by providing risers to the ground surface. Prior to placement in a sanitary landfill any subsurface improvement that might come into contact with active materials should be protectively coated. Access manholes in sanitary sewer lines should provide a means for monitoring the line profile. Natural gas mains should be provided with valves near and exterior to the landfill interface if automatic shutoff instrumentation has not been provided. Individual gas services should be provided by shutoff valves next to the mains.

Maintenance requirements on sanitary landfills should be stringent. Gas control devices or safeguards should be maintained at all times in good working order.

Detection of incipient structural deficiency in an architectural or structural component is usually visual. Upon noticing a deficiency, the connections of the structure should be suspected and reference should be made to the original building plans and design calculations, if any. Surface improvements should be maintained in good condition and subsurface improvements installed within a sanitary landfill should be repaired or replaced when the structural factor of safety is less than 1.0.

CONCLUSIONS

(1) Landfill gases may migrate a considerable distance (700 feet has been recorded) from the fill, depending on the nature of the soil formations around the fill.

(2) Gas movement from sanitary landfills takes place by molecular diffusion and convective gas transport mechanisms. The rate of this transfer is determined by the permeability characteristics of the soil formations around the fill.

(3) Landfill produced gases can and should be controlled and directed to areas of harmless dispersal.

(4) Control systems installed during this study have proven effective in interrupting the flow of migrating gases. Natural and mechanical barriers may be provided, ventilation devices have been demonstrated to be effective, and special design techniques are logically promising.

(5) Landfills are potential sources of pollutants to usable underground waters. Water pollution from landfill sources may be prevented by means other than prohibiting landfills over underground usable water. The Leachate Pollution Index, developed during the study, is a new and effective means of quantifying and predicting the leachate pollution potential from sanitary landfills.

(6) Subsidence of the surfaces of sanitary landfills and dumps is a prime inhibitor in planning for future use of completed sites. Subsidence occurs in three phases: (a) initial subsidence; (b) intermediate subsidence; and (c) ultimate subsidence. The three phases of subsidence are subject to control. Initial subsidence and ultimate subsidence investigations have resulted in delineation of control parameters and formulation of a method of quantification to predict ultimate subsidence under controlled conditions.

Differential settlement may be incurred as a result of loading the landfill surface. Buildings, surface improvements, and subsurface structures can suffer damage or destruction if constructed on sanitary landfills without proper regard for the potential differential settlement.

(7) The most frequently reported use of completed sanitary landfills has been recreational. A significant number of uses as industrial, commercial, and residential were also reported.

Planning, prior to landfilling, for use of the completed landfill surfaces has been reported to vary from nonexistent to almost comprehensive, with corresponding successes. Planning which included gas control was not reported. Planning for water pollution prevention has been effective. Planning as a function of subsidence and subsequent differential settlement generally appears to be inherently cognizant of initial subsidence only, in many instances.

(8) Many existing building codes do not provide for protection of structures, located adjacent to, or on, refuse fills, from the fire and toxic hazards of landfill produced gases. However, some Building Officials are providing for this protection by enforcing policy memoranda.

RECOMMENDATIONS

(1) Landfill locations should be selected to be compatible with relevant elements of a functional general plan which includes: (a) a land use plan, solid waste plan, and street and highway plan; and (b) community ordinances which include a sanitary landfill code, water pollution laws, building code, plumbing code, electrical code, excavation and grading code, and engineering regulations and standard specifications. A recreational plan could be beneficially included in (a) above for many communities.

Many landfills could be designed and constructed as an engineered product with concern for the future property value, manifesting the potential of the completed site.

(2) Gas movement, if any, adjacent to existing sanitary landfills should be detected and traced. Gas monitoring programs should be established. Local governmental agencies should implement staff technical capabilities. Gas control system economics should be quantified to develop optimally costed systems.

Improved gas control technology can result from further research. Broader application can result from dissemination of available knowledge to educators, engineers, and public officials.

(3) Leachate pollution prevention studies should be conducted, in cooperation with State water pollution officials, to establish the conditions under which selected manufactured leachate pollution barriers may be utilized over strata bearing usable waters.

Leachate characteristics should be examined as a function of permeability through a variety of porous media to establish capacities to prevent pollution of usable underground water.

(4) In order to minimize subsidence and related effects, the ratio of inert cover material to biodegradable material can be increased without detrimental effects on the economics of "landfilling only" as compared to the next cheapest alternative, "incineration and residue landfilling."

The technical benefits of materials control will also diminish subsidence effects but is probably not politically attainable. Materials control should be continuous during collection, transfer, and disposal to minimize heterogeneity. Segregation by organic content and bulk reprocessing and reclamation, and pulverization such as hammermilling and comminuting will also aid to minimize heterogeneity.

Any landfill that is in the path of urban development and expected to be used within the next 20 years should be periodically monitored for subsidence.

(5) "Model Ordinance For Control of Sanitary Landfills" is now available. This should be adopted in ordinance or code form and used in concert with "Uniform Standards for Location, Design, Construction, and Maintenance of Sanitary Landfills Subject to Sanitary Landfill Code" or other local or regional standards.

APPENDIX A

LIST OF REFERENCES CITED

A

APPENDIX A

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APPENDIX B

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B

APPENDIX B

BIBLIOGRAPHY OF LITERATURE REVIEWED

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APPENDIX C

SUBSURFACE INVESTIGATION
AT
SELECTED LANDFILL SITES

C

APPENDIX C

FIELD INVESTIGATION

Introduction

Pursuant to authorization from Engineering-Science, Inc., a subsurface investigation was conducted by Converse, Davis and Associates at four sanitary landfills identified as: (1) Site 1; (2) Site 3; (3) Site 12; and (4) Site 13.

The purpose of this investigation was to log the materials encountered during subsurface exploration, to determine the in situ unit weights and moisture contents, and to obtain bulk samples for laboratory analysis. Representative samples of the materials encountered in the borings were obtained in the field and subsequently pulverized. Representative samples of about one-half cubic foot were shipped to the Engineering-Science, Inc. Research and Development Laboratory in Oakland, California.

Two borings were drilled at each of the sites noted above and penetrated through the sanitary landfill except at Site 12 where massive concrete was encountered at a depth of about 55 feet in each boring and could not be penetrated with the drilling equipment. The locations of the borings made at each site are shown on Drawing No. 1, "Location of Borings."

Summary of Data

The results of our investigation are presented in Table I, "Summary of Data" and shows the computed in situ wet density, in situ dry density, moisture contents, and the weight of rocks and metal removed from the samples.

Continuous logs of the materials encountered in the borings were obtained in the field by one of our field engineers. The boring logs are presented on attached drawings. The depth that ground water was encountered in the borings is also shown on the various drawings of the boring logs.

Field Equipment

The borings were advanced by utilizing a truck-mounted bucket auger rig equipped with a 13-inch diameter drilling bucket especially designed and constructed for drilling sanitary landfill.

In some cases and to prevent sloughing in of material from the sides of the boring above the sample increment, the boring was advanced from one sampling depth to another by utilizing either a conventional 16-inch diameter earth-type drilling bucket or a 16-inch diameter rock-type drilling bucket. In most cases, the sample itself was excavated with the special 13-inch diameter drilling bucket. The sample locations are shown on the boring logs.

Field Density Determinations

The field density of the refuse was obtained by sampling and weighing all material collected from a measured sample interval. The sample volume was determined by measuring the depth of the sample increment with a weighted steel tape referenced to a fixed point at the ground surface. The diameter of the boring was visually estimated by use of a 12-inch long bar fixed at right angles to the steel tape.

The material removed from the boring was dumped into 55-gallon steel drums with the use of a plywood hopper. The weight of the materials was determined to the nearest 0.1 pound, and the samples were then dumped onto plywood sheets and thoroughly mixed. During the mixing operation, rocks larger than 3/4 inches in diameter and metals were removed by hand.

Moisture content of the refuse was determined by obtaining from one to three representative samples and drying in an electric oven at 80 degrees Centigrade for a minimum period of 12 hours.

After mixing and moisture content sampling, the bulk sample was quartered and loaded into a polyethylene bag contained inside a heavy wall, paper bag. The bags were sealed to prevent loss of moisture.

The samples were then shipped to our laboratory in Pasadena where they were stored for processing. Processing consisted of pulverizing the individual bulk samples in a hammermill in which the material was graded to a maximum size of about 1/4 inch. Approximately one-half cubic foot of each sample was retained, sealed in a heavy wall, polyethylene bag and shipped to the Engineering-Science, Inc. laboratories in Oakland, California.

Accuracy of Density Results

Field measurements, related to density determinations, were accurate to the extent of reliably measuring the volume of the sample interval. It is considered that the diameter and depth of the sample were measured to an accuracy of between 10 and 15 percent. Determination of moisture content was also subject to error in view of the variation in type of refuse encountered. In total, the calculated dry density of the sampled material should have an accuracy of 15 to 20 percent.

TABLE I
SUMMARY OF DATA

Site	Boring No.	Sample No.	Sample Depth (feet)	Wet Weight of Sample (pounds)	In Situ Wet Density (pcf)	No. of Moisture Tests	Moisture Content Percent			In Situ Dry Density (pcf)	Weight of Gravel and Metals Removed(lbs.)	Percent by Wt. of Gravel and Metals Removed
							Min.	Max.	Avg.			
1	1	1	13.0-15.0	274.3	149.0	1	-	-	53.4	97.2	-	-
	1	2	17.0-18.0	92.0	100.0	1	-	-	37.0	73.0	4	4.3
	1	3	23.0-26.0	370.2	134.0	2	28.5	54.4	30.4	102.9	1	0.3
	1	4	26.5-29.3	218.8	83.6	1	-	-	20.9	69.3	1	0.4
	1	5	33.2-34.8	119.3	86.5	1	-	-	70.8	50.6	10	8.4
	1	6	35.2-36.8	96.3	69.7	1	-	-	16.5	59.8	0	0
	1	7	40.0-41.5	111.2	85.0	1	-	-	64.5	51.7	0	0
	1	8	45.0-50.0	460.9	99.8	2	16.5	80.5	48.5	67.2	0	0
	1	9	56.5-60.0	425.2	131.7	2	19.5	25.2	22.4	107.5	17	4.0
	1	10	63.5-64.8	159.0	129.3	2	29.6	70.3	50.0	86.3	2	1.2
	1	11*	68.5-70.0	288.6	140.0	1	-	-	24.5	112.3	15	5.2
	1	12	71.0-75.5	463.2	111.0	3	28.6	38.0	33.8	83.0	10	2.2
1	2	1	17.0-22.2	419.3	86.6	2	56.3	104.9	80.6	47.9	23	5.5
	2	2*	27.0-28.7	308.3	200.0	2	19.5	29.6	24.6	161.0	12	3.9
	2	3	30.0-32.0	138.0	74.7	2	65.4	87.7	76.6	42.3	8	5.8
	2	4	35.0-40.0	501.7	111.3	2	57.9	67.2	62.6	68.6	15	3.0

* Density data invalid due to caving and raveling during sampling.

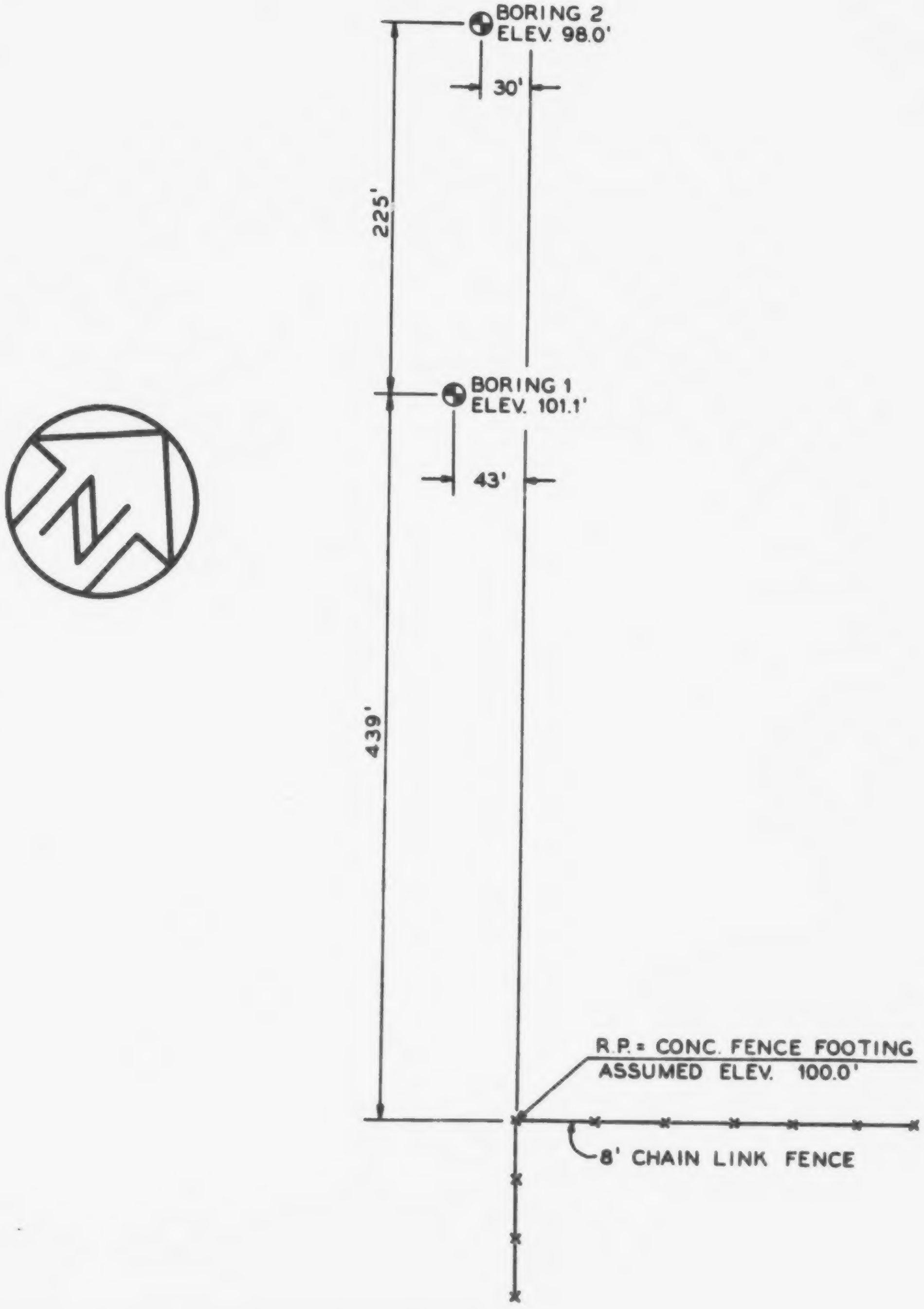
TABLE I (Cont'd.)
SUMMARY OF DATA

Site	Boring No.	Sample No.	Sample Depth (feet)	Wet Weight of Sample (pounds)	In Situ Wet Density (pcf)	No. of Mois- ture Tests	Moisture Content Percent Min.	Max.	Avg.	In Situ Dry Density (pcf)	Weight of Gravel and Metals Removed(lbs.)	Percent by Wt. of Gravel and Metals Removed
1	2	5	45.8-49.0	306.7	104.0	2	21.5	33.8	27.7	81.7	9	2.9
	2	6	55.0-57.7	186.6	75.8	2	22.3	32.9	27.6	59.5	8	4.3
	2	7	60.0-65.0	91.5	31.7	2	31.7	37.8	34.8	67.8	5	1.2
	2	8	70.2-75.1	434.4	97.5	3	17.8	67.0	41.3	68.8	11.5	2.6
	2	9	80.0-81.3	100.8	82.0	2	30.9	40.0	35.4	60.5	11	10.9
3	1	1	10.0-15.2	264.9	54.8	2	26.9	27.4	27.2	43.1	12	4.5
	1	2	20.0-25.0	240.9	52.3	2	34.6	50.6	42.6	36.7	11	4.6
	1	3	30.0-31.8	92.6	54.7	2	61.3	97.4	79.3	30.4	5	5.4
3	2	1	3.0- 7.3	239.3	60.0	2	33.7	33.9	33.8	44.9	21	8.8
	2	2	13.0-18.0	232.9	50.5	3	22.6	39.4	28.5	39.3	11	4.7
	2	3	23.0-28.0	313.9	68.0	2	26.1	32.8	29.4	52.5	12.5	4.0
12	1	1	14.0-15.8	128.3	75.8	2	56.4	59.7	58.0	47.5	5.5	4.3
	1	2	15.8-17.0	99.6	92.5	2	34.4	34.8	34.6	68.7	2.5	2.5
	1	3	17.0-22.0	311.3	67.5	2	29.5	43.6	36.6	49.4	8	2.6
	1	4*	28.0-28.5	108.1	-	2	46.4	48.4	47.6	-	5	4.6
	1	5*	30.0-35.1	1063.8	-	-	-	-	-	-	30	2.8

* Hole caved and ravelled during sampling.

TABLE I (Cont'd.)
SUMMARY OF DATA

Site	Boring No.	Sample No.	Sample Depth (feet)	Wet Weight of Sample (pounds)	In Situ Wet Density (pcf)	No. of Moisture Tests	Moisture Content Percent			In Situ Dry Density (pcf)	Weight of Gravel and Metals Removed(lbs.)	Percent by Wt. of Gravel and Metals Removed
							Min.	Max.	Avg.			
12	2	1	8.0-13.0	226.9	49.0	2	19.8	45.9	32.8	36.9	8	3.5
	2	2	18.0-22.0	217.3	70.2	2	35.4	54.1	44.8	48.5	15	6.9
	2	3	27.0-32.0	224.4	48.6	2	38.9	52.1	45.5	33.4	16	7.1
	2	4	37.0-41.2	418.9	109.2	2	9.4	12.1	10.8	98.6	77	18.4
	2	5	41.2-46.2	370.4	80.0	2	27.0	35.1	31.0	61.1	16	4.3
13	1	1	5.0-10.0	247.3	53.5	2	40.9	60.1	50.5	35.6	28.5	11.5
	1	2	15.0-19.0	231.3	75.3	2	40.7	73.4	57.0	47.9	12	5.2
13	2	1	5.0-10.3	238.6	48.5	2	14.6	83.2	48.9	32.6	23	9.6


BORING 2
ELEV. 98.0'
30'
225'
BORING 1
ELEV. 101.1'
43'
N
439'
R.P. = CONC. FENCE FOOTING
ASSUMED ELEV. 100.0'
8' CHAIN LINK FENCE

LOCATION OF BORINGS

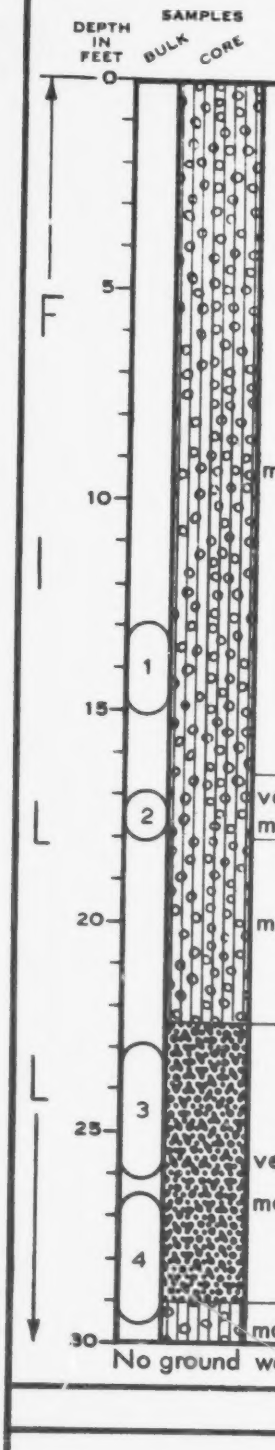
SITE 1
Subsurface Investigation of Sanitary Landfill

DATE: Oct. 21, 1968 | SCALE: 1"=100'

LOG OF BORING 1

ELEVATION: 101.1'

DATE DRILLED: Sept. 23, 1968



DESCRIPTION OF MATERIAL					REMARKS
moist	dense	gray brown	SILTY SAND, fine to coarse	& 25% gravel, cobbles & boulders to 15" & concrete & occ. organic (grass, twigs & palm leaves)	very difficult drilling
				& 40% rubble (concrete to 20", asphalt pieces & length of 2" pipe)	
		dark gray		& 10% gravel to 3"	
very moist	loose	black		&25% organic (paper, twigs, etc)	
moist	dense	gray		& 30% gravel & cobbles to 6"	difficult drilling
very moist	very soft & loose	brown & black & gray	REFUSE & 25% silty sand & 5% gravel to 3" (paper, plastic, wood, grass twigs, leaves, glass, metal, etc.)		
moist	dense	gray	SILTY SAND, &30% gr. to 3"		

No ground water encountered.

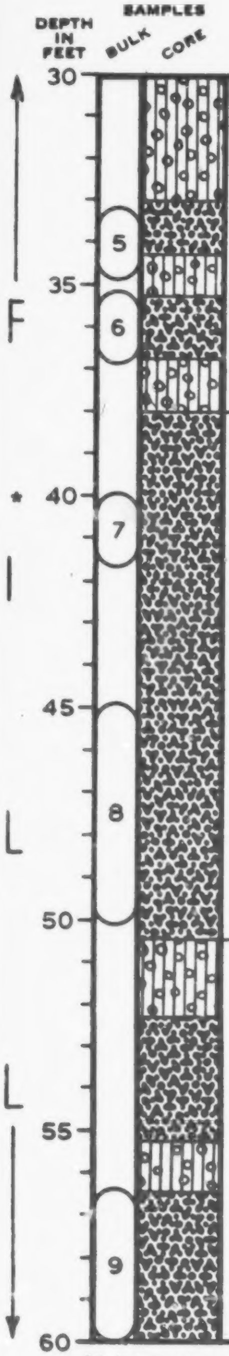
(continued)

SOIL INVESTIGATION

SITE 1
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 1
(continued)

DATE DRILLED: Sept. 23 & 24, 1968



	DESCRIPTION OF MATERIAL			REMARKS
moist	dense	gray	SILTY SAND, fine to cr. & 30% gravel to 3"	
	very loose	dk. gr. brown	REFUSE & 10 % sand & gravel	
	dense	gray	SILTY SAND & 30% gr. to3"	
	very loose	dk. gr. brown	REFUSE & 25 % silty sand & 5% gravel to 3" & metal	
	dense	gray	SILTY SAND, &30% gr. to3"	
wet	very loose	black	REFUSE &10%silty sand & gravel to 3" & metal & frequent tires	water seepage below 40'
very moist	dense	gray	SILTY SAND, fine to cr. & 20% gravel to 3"	
	very loose	black	REFUSE & 10% silty sand &5 % gravel & metal	
	dense	gray	SILTY SAND, &10% gr. to3"	
	very loose & dense	black & gray	REFUSE &35% silty sand & 10% gravel to 3" & metal (continued)	

*Water seepage below 40'.

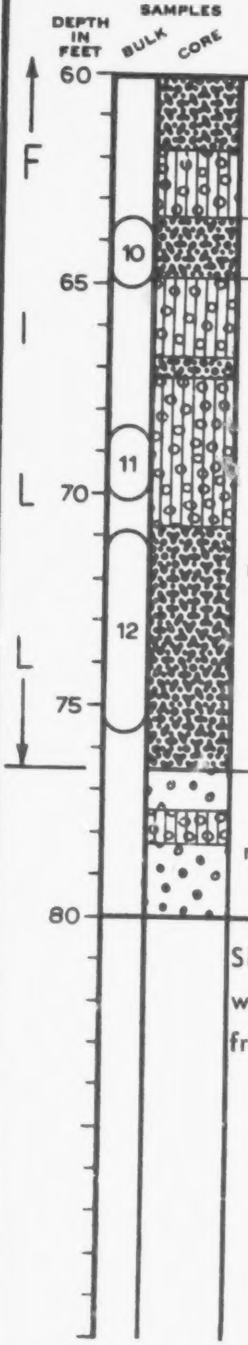
SOIL INVESTIGATION

SITE 1
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 1

(continued)

DATE DRILLED: Sept. 24 & 25, 1968



DESCRIPTION OF MATERIAL				REMARKS
very moist to wet	very loose	black	REFUSE &10% silty sand & 5% gravel to 3" & metal	
	dense	gray	SILTY SAND, fine to cr. &25% gravel & cbl. to 6"	
wet	very loose	black	REFUSE &15% silty sand & 5% gravel to 3" & metal	small amounts of water formed overnight at 64.5'
very moist	dense	gray	SILTY SAND, & 25% gravel & occasional cobbles to 6"	difficult drilling- slight caving
	v. soft	black	← refuse	
	dense & very loose	gray & black	fine to coarse & 50% refuse & 20% gravel & occ. cobbles to9"	
	very loose	black	REFUSE & 5% silty sand & 5% gravel to 3" & metal	
moist	dense	gray	SAND, fine to coarse & 30% gravel & cobbles to 6" ← silty sand	

Slight seepage below 40'- small amount of water formed overnight at 64.5'- slight caving from wet sands below 65' to 76.5'.

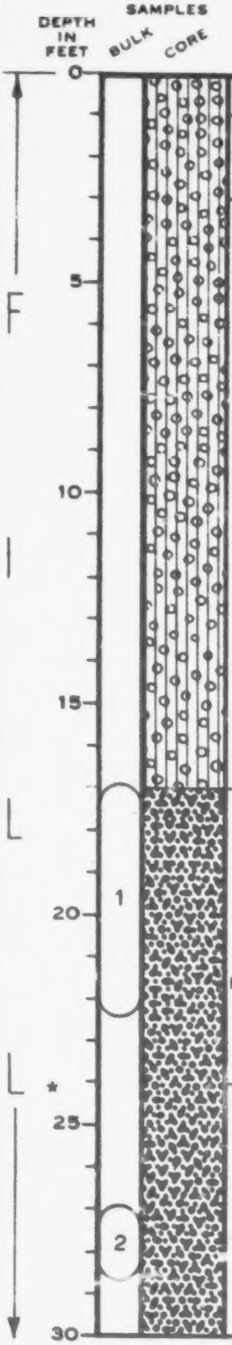
SOIL INVESTIGATION

SITE 1
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 2

ELEVATION: 98.0'

DATE DRILLED Sept. 26, 1968



DESCRIPTION OF MATERIAL				REMARKS
dry slightly moist moist	medium dense	gray brown & dark gray	SILTY SAND, fine to coares & 30% gravel & cobbles to 6" & alt. silty sand & 30% rubble (chunks of concrete & a. c. to 12", & occasional trash, wood, etc.)	
very moist wet	very loose	black & gray	REFUSE & 10% silty sand streaks & 5% gravel to 3" & metal	slow drilling

*perched water- seepage

(continued)

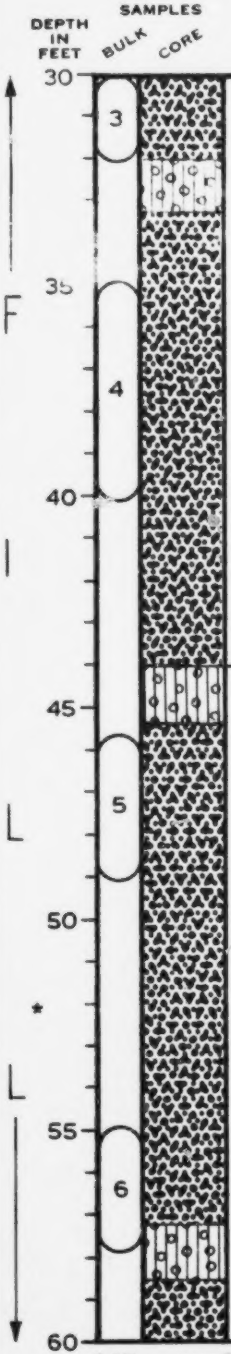
SOIL INVESTIGATION

SITE 1

Subsurface Investigation of Sanitary Landfill

LOG OF BORING 2
(continued)

DATE DRILLED: Sept. 26 & 27, 1968



DESCRIPTION OF MATERIAL				REMARKS
very moist	very loose	black & gray	REFUSE &5% gravel to 3" &10% silty sand stk. &metal	
	dense	gray	SILTY SAND, fine to cr. & 30% gr. & cbl. to 6"	
	very loose	black & gray brown & gray	REFUSE & 10% silty sand streaks & 5% gravel to 3" & metal	
moist	dense	gray	SILTY SAND, fine to cr. &30% gr. & cbl. to 6"	
	very loose	black & gray brown & gray	REFUSE &10% silty sand streaks & gravel to 3" & metal	6" water formed overnight at 52' from seepage at 24' to 30'
	dense	gray brown	SILTY SAND, fine to cr. &30% gr. & clb. to 9"	
	very loose	black & gr. brn.	REFUSE & occ. gravel to 3" & metal (continued)	

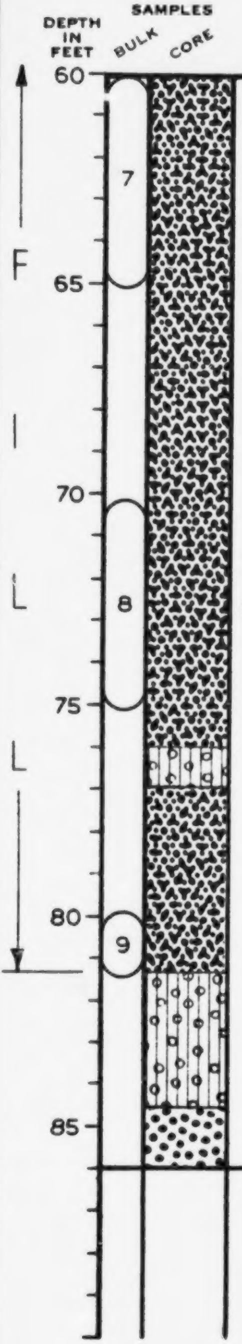
*6" water formed overnight at 52'

SOIL INVESTIGATION

SITE 1
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 2
(continued)

DATE DRILLED Sept. 27 & 28, 1968

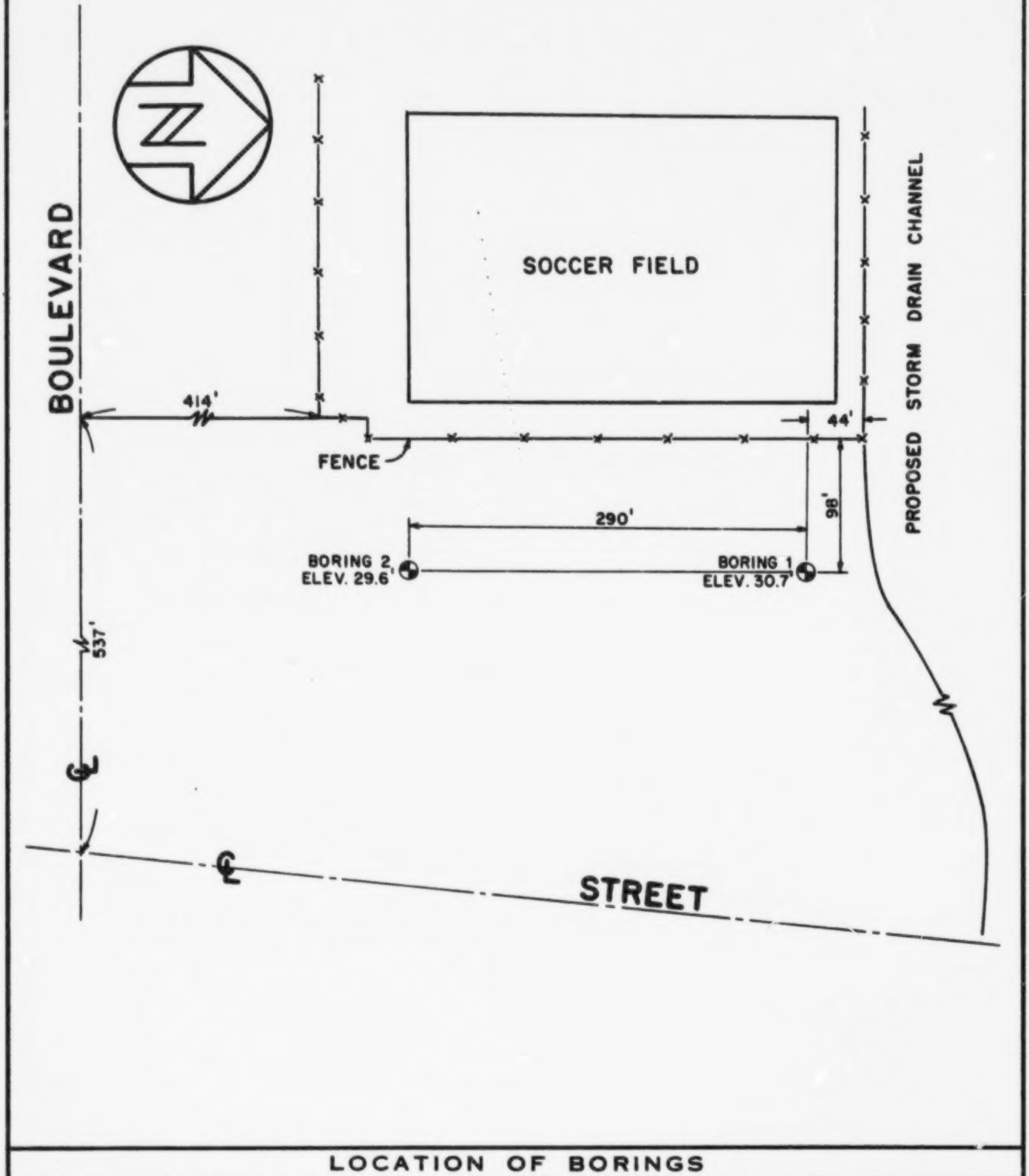


DESCRIPTION OF MATERIAL					REMARKS
moist	very loose & dense	black & gray brown & gray	REFUSE	& occasional gravel to 3" & metal & 15% silty sand streaks to 3" with 30% gravel to 3"	
	dense	black	SILTY SAND & 30% gr. to 3"		
	very loose	& gray brown	REFUSE	& metal pieces to 5% & occasional gravel to 3"	
	dense	gray	SILTY SAND, fine to coarse	& 30% gravel	
			SAND, fine to coarse	& cobbles to 9"	

Only small amount of water above 52' encountered.

SOIL INVESTIGATION

SITE 1
Subsurface Investigation of Sanitary Landfill


BOULEVARD
N
SOCCER FIELD
PROPOSED STORM DRAIN CHANNEL
414'
44'
FENCE
290'
98'
BORING 2
ELEV. 29.6'
BORING 1
ELEV. 30.7'
537'
℄
℄
STREET

LOCATION OF BORINGS

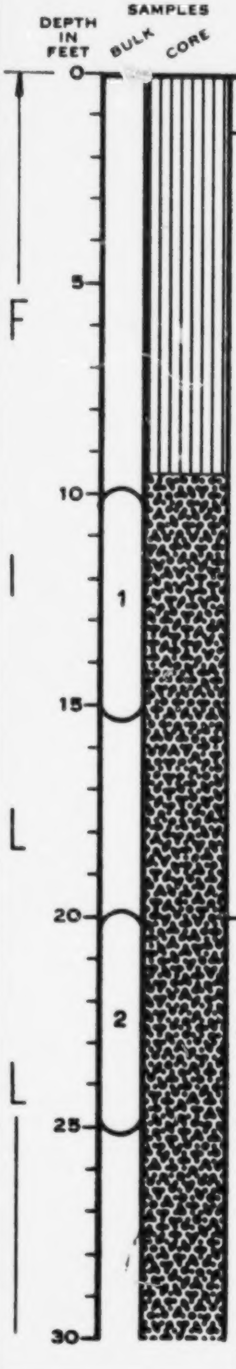
SITE 3
Subsurface Investigation of Sanitary Landfill

DATE: Oct. 21, 1968	SCALE: 1" = 100'

LOG OF BORING 1

ELEVATION 30.7'

DATE DRILLED Sept 28, 1968


DEPTH IN FEET
SAMPLES
BULK
CORE
0
5
10
15
20
25
30
1
2
F
I
L
L

DESCRIPTION OF MATERIAL					REMARKS
dry	stiff	light brown & gray brown	SANDY SILT		
moist				& clayey silt	
		blue gray & black		& alt. silty clay & silty sand & occ. refuse	
	very loose	black & gray & white	REFUSE & 5% rubble (metal & brick)	& 10% clayey silt	difficult slow drilling in refuse
very moist				& 5% silt	

No ground water encountered. (continued)

SOIL INVESTIGATION

SITE 3
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 1
(continued)

Sept. 28, 1968

DEPTH IN FEET	SAMPLES BULK	SAMPLES CORE	DESCRIPTION OF MATERIAL				REMARKS
30 FILL	3	▓	very moist	very loose	black & gr. & wh.	REFUSE & 5% silt &5% rubble &30% silty clay	
		▨		stiff	dark gray	SILTY CLAY	
35							

No ground water encountered.

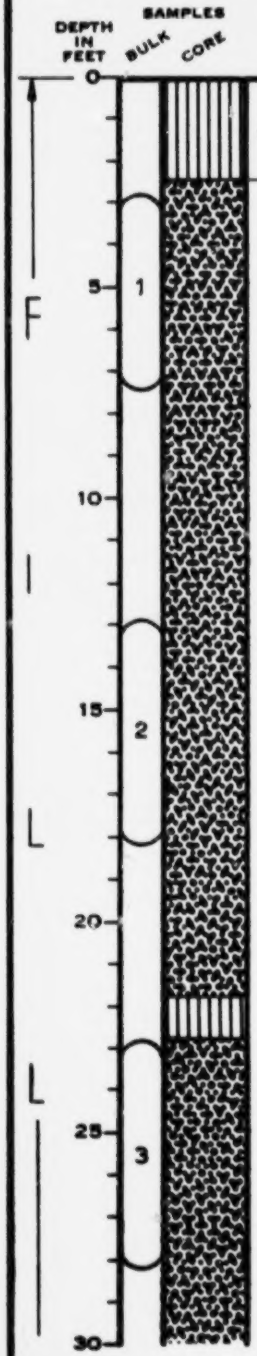
SOIL INVESTIGATION

SITE 3
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 2

ELEVATION: 29.6'

DATE DRILLED: Sept. 30, 1968 & Oct. 1, 1968


DEPTH IN FEET
SAMPLES
BULK
CORE
0
5
10
15
20
25
30
1
2
3
F
I
L
L

DESCRIPTION OF MATERIAL					REMARKS
dry	stiff	gray & brown	SILT & SILTY CLAY		
moist	very loose	black & gray & white	REFUSE & 5% rubble (metal & concrete)	& 20% silty sand & sandy silt	slow drilling in refuse
	stiff	blu. gr.	← sandy silt		
	very loose	black & gray & white		& 20% sandy silt & clayey silt	

No ground water encountered.

SOIL INVESTIGATION

SITE 3
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 2
(continued)

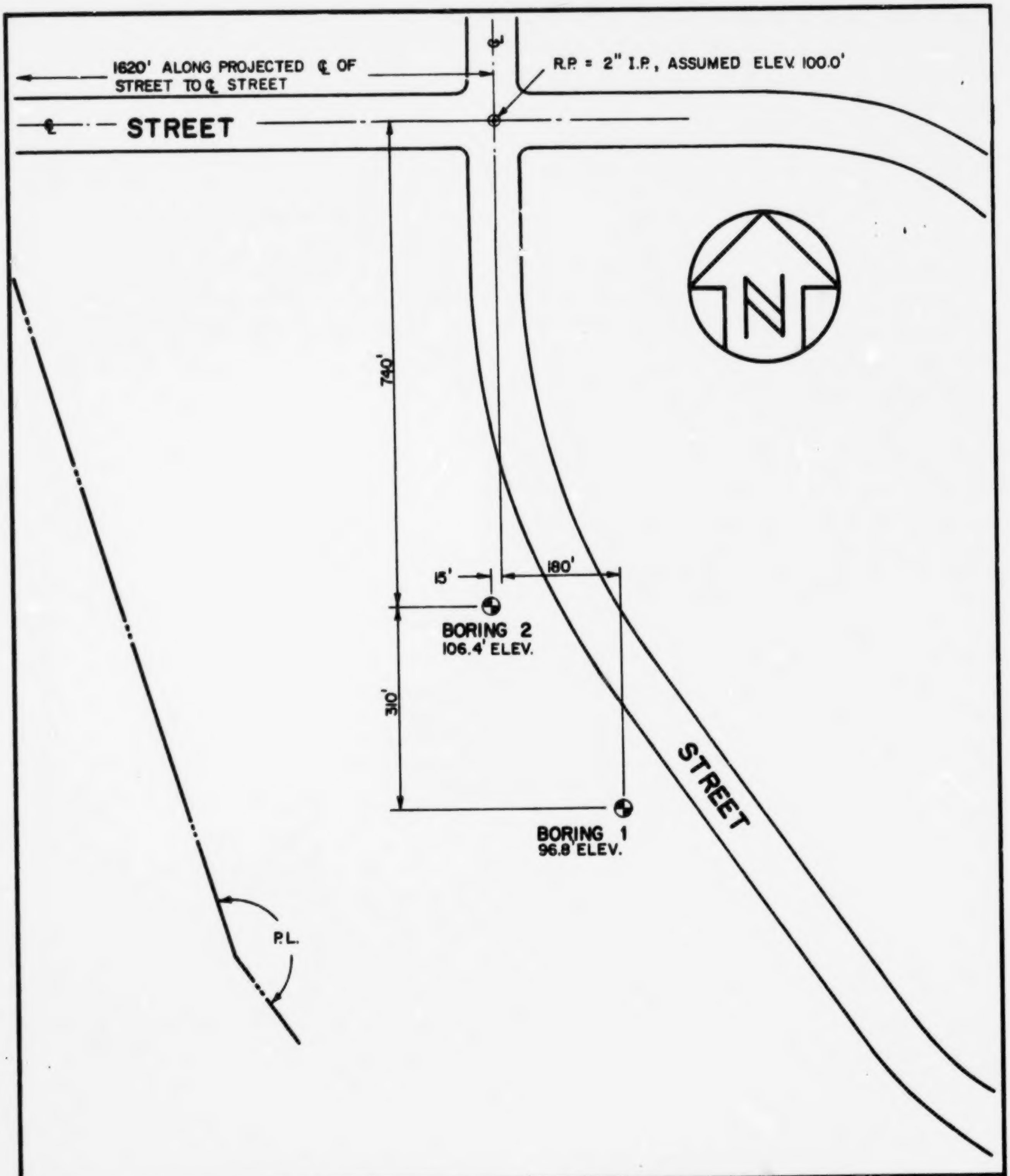
Oct. 1, 1968

DEPTH IN FEET	SAMPLES BULK	SAMPLES CORE	DESCRIPTION OF MATERIAL				REMARKS
30 FILL			moist	very loose	black & gray & white	REFUSE & 5% rubble &30% sandy silt & clayey silt	
				stiff	gr. brn. &dk. gr.	SANDY SILT & SILTY CLAY	
35				medium dense	light brown	SILTY SAND, fine	

No ground water encountered.

SOIL INVESTIGATION

SITE 3
Subsurface Investigation of Sanitary Landfill


1620' ALONG PROJECTED ℄ OF
STREET TO ℄ STREET
R.P. = 2" I.P., ASSUMED ELEV. 100.0'
℄
℄ STREET
N
740'
15'
180'
BORING 2
106.4' ELEV.
310'
BORING 1
96.8' ELEV.
STREET
P.L.

LOCATION OF BORINGS

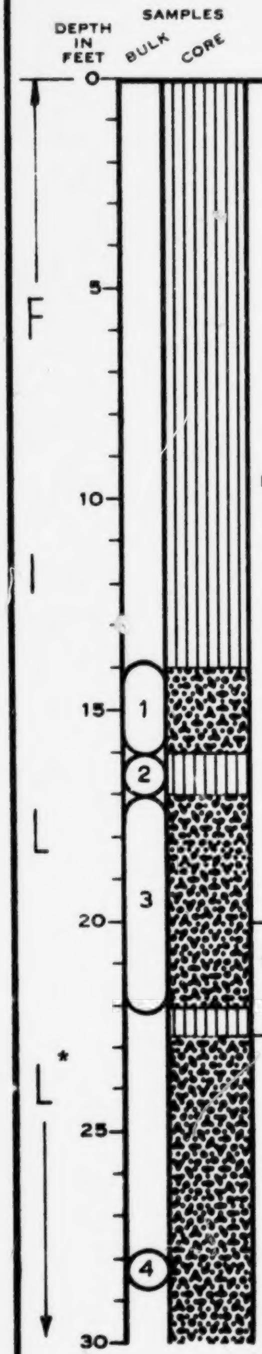
SITE 12
Subsurface Investigation of Sanitary Landfill

DATE: Oct. 21, 1968	SCALE: 1" = 200'

LOG OF BORING 1

ELEVATION 96.8'

DATE DRILLED Oct. 2, 1968



DESCRIPTION OF MATERIAL					REMARKS
moist	stiff	brown & gray	SANDY SILT to CLAYEY SILT		
		dark blue gray		& occasional refuse	
	very soft	dk. gray & white	REFUSE	& 5% rubble & 5% sandy silt & clayey silt	
	firm & soft	blue gr. & black	SANDY SILT & CLAYEY SILT	& 50% refuse	
	very soft	black & gray & white	REFUSE	& 20% sandy silt	
very moist					
	firm		← sandy silt		
wet	very soft			& 5% rubble	
		black		& 50% silt & organic stain & occ. rubble	

* seepage below 23'

(continued)

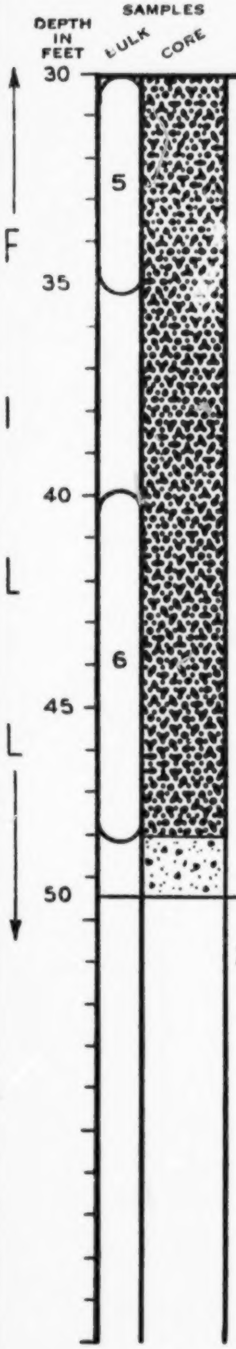
SOIL INVESTIGATION

SITE 12
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 1

(continued)

Oct. 2 & 3, 1968


DEPTH IN FEET
SAMPLES
BULK
CORE
30
35
40
45
50
5
6
F I L L

DESCRIPTION OF MATERIAL				REMARKS
wet	very soft	black	REFUSE & 50% silt & occasional rubble (metal, concrete, etc.)	
	hard	gray	CONCRETE slab **	

**could not break through

2' of water formed overnight with hole open to 34'

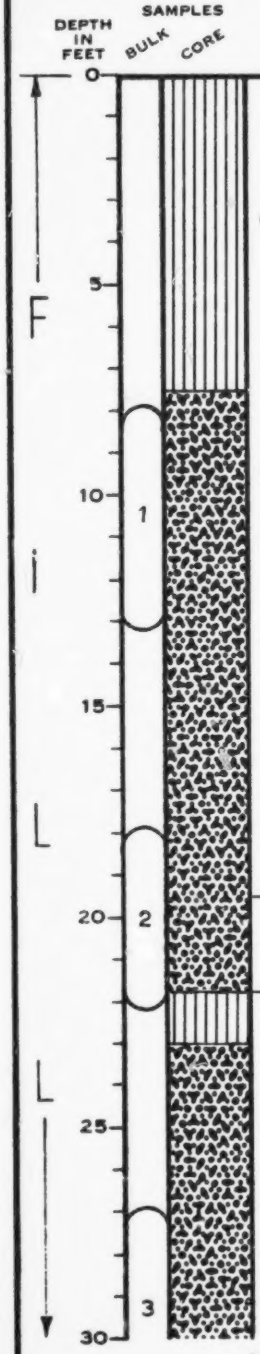
SOIL INVESTIGATION

SITE 12
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 2

ELEVATION: 106.4'

DATE DRILLED: Oct. 4, 1968



DESCRIPTION OF MATERIAL					REMARKS
dry to slightly moist to moist	firm	light gray brown & blue gray	SANDY SILT, SILT & SILTY SAND, fine	& 10% refuse	
	very soft	black & gray & white	REFUSE & 5% rubble	& 20% sandy silt streaks to 6"	slightly decomposed
very moist		black		& 50% silt, organic stained	very decomposed
moist	firm	gray	SILT & occasional refuse		very decomposed
	very soft	black & gray & white	REFUSE & 5% silt & 5% rubble		

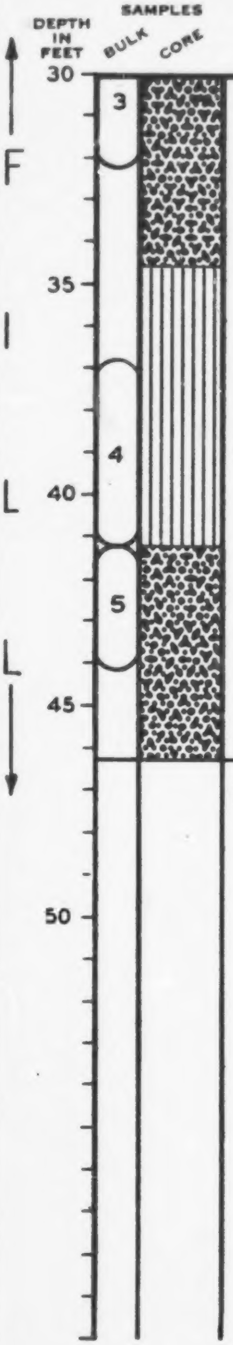
No ground water encountered. (continued)

SOIL INVESTIGATION

SITE 12
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 2
(continued)

Oct. 4, 1968

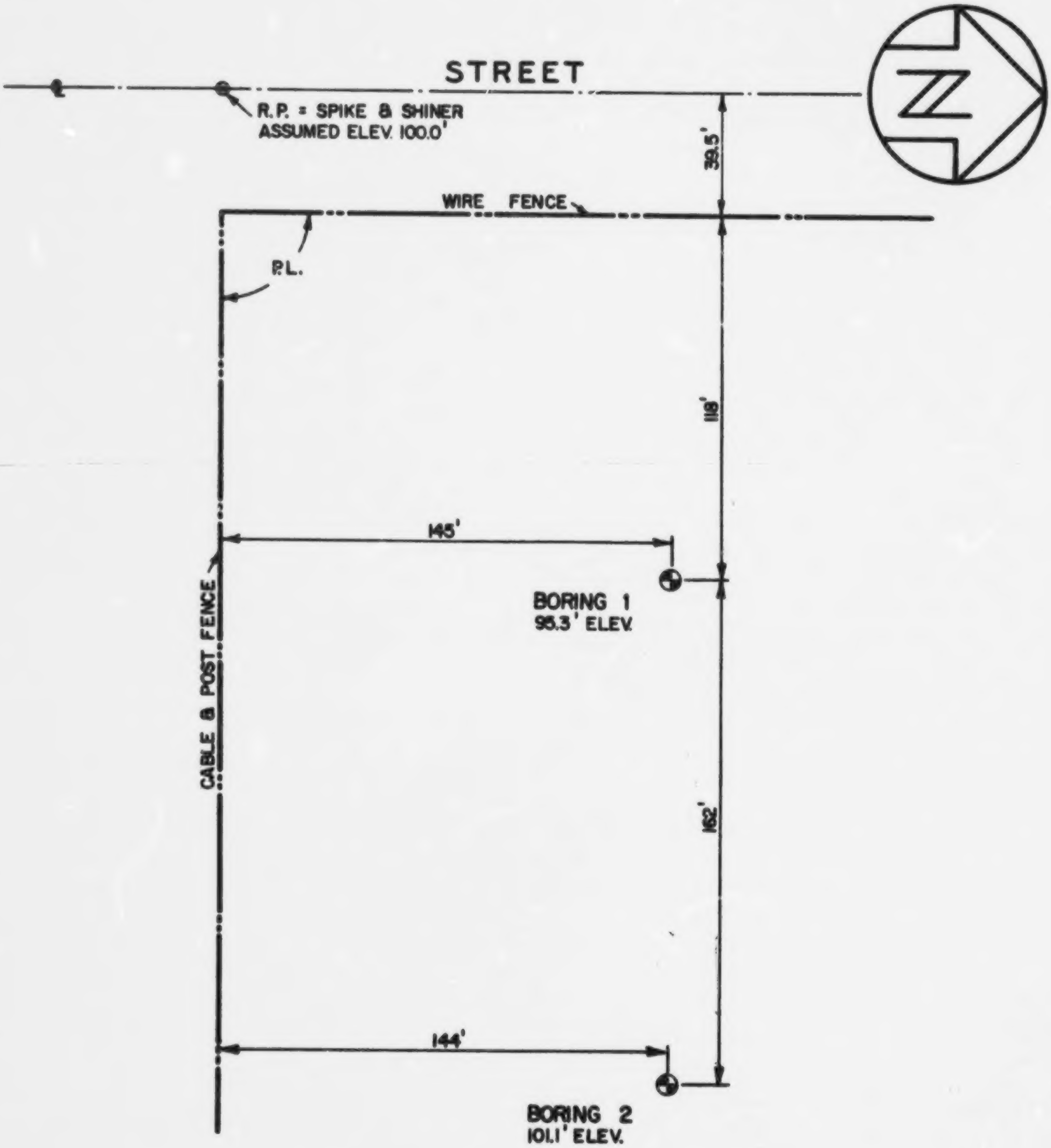

SAMPLES
DEPTH IN FEET
BULK
CORE
30
3
F
35
I
4
L
40
5
L
45
50

DESCRIPTION OF MATERIAL					REMARKS
moist	very soft	black & gray & white	REFUSE & 5% rubble	& 5% silt	slightly decomposed
	soft	black		& 20% silt	
				& 40% silt	
			SANDY SILT & 5% refuse & 20% rubble (concrete to 12", brick, a. c., metal, etc.)		
	very soft	black & light gray	REFUSE & 10% silt & rubble		

No ground water encountered.

SOIL INVESTIGATION

SITE 12
Subsurface Investigation of Sanitary Landfill


STREET
N
R.P. = SPIKE & SHINER
ASSUMED ELEV. 100.0'
39.5'
WIRE FENCE
P.L.
118'
145'
BORING 1
95.3' ELEV.
CABLE & POST FENCE
162'
144'
BORING 2
101.1' ELEV.

LOCATION OF BORINGS

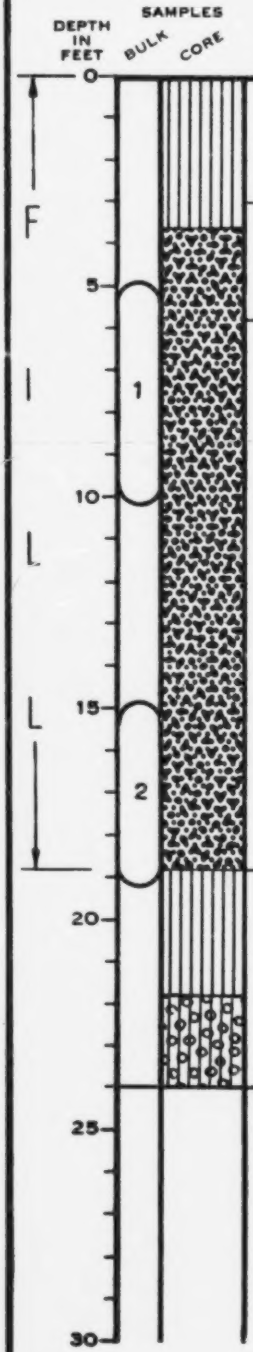
SITE 13
Subsurface Investigation of Sanitary Landfill

DATE: Oct. 21, 1968	SCALE: 1" = 50'

LOG OF BORING 1

ELEVATION: 95.3'

DATE DRILLED: Oct. 1, 1968


DEPTH IN FEET
SAMPLES
BULK
CORE
0
5
10
15
20
25
30
F
I
L
L
1
2

DESCRIPTION OF MATERIAL				REMARKS
dry	soft	gray brown	SANDY SILT, CLAYEY SILT & SILTY CLAY	
moist	very loose	black & brown & gray	REFUSE & 30% sandy silt & 10% rubble (metal, concrete, etc.)	
very moist		black		
moist	stiff	dark gray	SANDY SILT	
	dense		SILTY SAND, fine	

No ground water encountered.

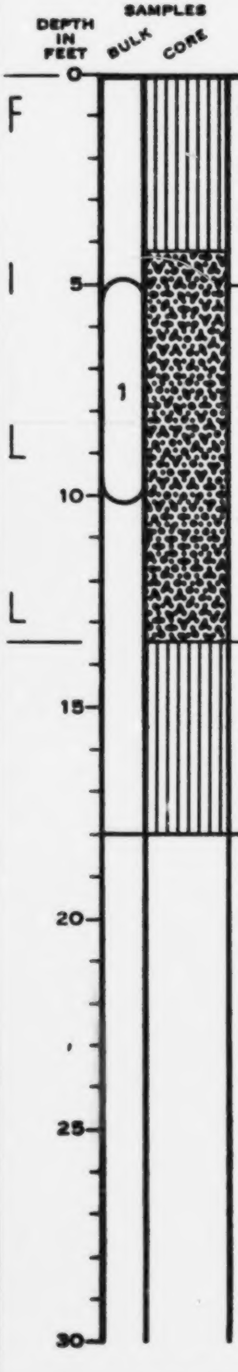
SOIL INVESTIGATION

SITE 13
Subsurface Investigation of Sanitary Landfill

LOG OF BORING 2

ELEVATION: 101.1'

DATE DRILLED: Oct. 1, 1968


DEPTH IN FEET
SAMPLES
BULK
CORE
0
5
10
15
20
25
30
1
F
I
L
L

DESCRIPTION OF MATERIAL					REMARKS
dry to moist	firm	gray brown to light brown	SANDY SILT, SILT & CLAYEY SILT		
very moist	very loose	black	REFUSE & 10% sandy silt & 10% rubble (metal, concrete, etc.)		
moist	stiff	blue gray brown	SILT & occasional alkali streaks	sandy clayey sandy	

No ground water encountered.

SOIL INVESTIGATION

SITE 13
Subsurface Investigation of Sanitary Landfill

APPENDIX D

TABLES

D

208

TABLE I-1

RESPONSE TO SHORT FORM QUESTIONNAIRE

Land Use	Number Reporting Use
Undetermined	10
Parks and Recreation	103
Industrial	31
Commercial	31
Agriculture	14
Home Sites	24
Airports	5
Sewage Treatment Facilities	3
School Facilities	12
Parking Lots	19
Storage Yards	20
Roads	5
Snow Dumps	3
Municipal Facilities	11
Fire Training Facilities	2
Mobile Home Park	2
Pistol Range	1
Arboretum	1
Military Facilities	1

TABLE I-2

SITE INVESTIGATIONS

Site No.	Physical Characteristics of Site	Present Use	Adjacent Property Use	Types of Structures on Landfills	Physical Conditions of Improvements	Problems and Solutions
1	Depth: 20 ft Age: 20 years Class II refuse	golf course restaurant garages and parking area	industrial, recreational	wood frame conventional foundation restaurant supported on caissons	uneven settlement at garages, walkways and paved areas, light poles out of plumb	some odors reported around garages and golf course, poor drainage in parking area, trouble growing grass on golf course, subsidence of garages, parking area and golf course
2	Depth: 100 ft Age: 7 years Class II refuse	recreational (ball park)	vacant residential	none	lawn areas appear to be in good condition	No odors, settlement of ball park and parking area
3	Depth: 19 ft Age: 15 years	trap and skeet range	industrial	wood frame clubhouse - rubbish replaced under structure by earth fill	excellent	none observed, plant growth reported inhibited
4	Depth: 28 ft Age: 20 years Class II refuse	trailer park	residential	wood frame on slabs, post and beams on piles, swimming pool	some settlement, gas service line to trailer reported broken	some settlement of trailer spaces and minor settlement of roads, gases controlled by Tiki burners, Vinyl barrier under slab over gravel
5	Depth: 110 ft Age: 11 years Class II refuse	Botanic Garden	residential	concrete block office and greenhouses, office building on floating slab foundation	cracks around front of office building-improvements are filled periodically. Temperature affects plant growth	gas seepage to adjacent property, gas found in greenhouses, cracks developed along edge of fill. Membrane installed under one greenhouse with vent system

TABLE I-2

SITE INVESTIGATIONS (Continued)

Site No.	Physical Characteristics of Site	Present Use	Adjacent Property Use	Types of Structures on Landfills	Physical Conditions of Improvements	Problems and Solutions
6	Depth: 80 ft Age: 10 years Class II refuse	department store	commercial residential	one story brick on a floating slab, grade beams on piles	floor has settled unevenly, minor cracking of building wall, settlement of parking area	no gas problems, settlement of structure and parking area causing breaks in utility lines. Light poles out of plumb. Grade in drainage channel lost
7	Depth: 14 ft Age: 6 years residential and commercial refuse	18 hole golf course	airport light industries	wood frame club house on floating foundation, parking lot and road	no problems	none
8	Depth: 25 ft Age: 30 years residential and commercial refuse, construction and demolition debris	parking lots marina, boat ramp	small building-marina administration, rest rooms, bait shop, and club houses	wood frame on piles	uneven roads, shifting of building, rupture of utility pipes	some odor but not serious, subsidence of structures
9	Depth: 25 ft Age: 20 years residential and commercial refuse, sewage sludge	none	vacant, light industry, ocean	none	----	subsidence, restricts construction potential

TABLE I-2

SITE INVESTIGATIONS (Continued)

Site No.	Physical Characteristics of Site	Present Use	Adjacent Property Use	Types of Structures on Landfills	Physical Conditions of Improvements	Problems and Solutions
10	Depth: 12 ft Age: One year residential and commerical refuse	none	vacant, evaporation ponds, ocean	none	----	none
11	Depth: 40 ft Age: 7 months residential, commercial and institutional refuse	roadway	residential	none	no problem	none
12	Depth: 4-5 ft Age: 2 years domestic garbage	grazing	farming	steel frame equipment, shade	no response	odors, from decaying organics
13	Depth: 20 ft Age: 8 years Class II refuse	industrial building, railroad spur and auto parking	park, freeway, industrial	one story wood frame on concrete floor slab, piles to natural ground	building is in excellent condition	railroad spur settles where railroad cars stand. Planters and walks cracked. Landscape sprinkler broken due to settlement. Fire sprinkler line broken due to settlement. Utility trenches filled with sand are acting as gas vents

TABLE I-2

SITE INVESTIGATIONS (Continued)

Site No.	Physical Characteristics of Site	Present Use	Adjacent Property Use	Types of Structures on Landfills	Physical Conditions of Improvements	Problems and Solutions
14	Depth: 20-40 ft Age: 6 years	industrial	industrial	tilt up concrete, floating floor, piles and grade beams	building partly on fill. Utilities not in fill. All good condition, few floor cracks	gas and odors, now controlled by vents through floor to roof. Explosive concentrations found by "Explosimeter"
15	Depth: 20 ft Age: 12 years	mobile home park	residential, commercial	wood frame on concrete slab	roads settled, swimming pool lost. Wash rooms settled. Electrical conduit is o.k.	sewers need perpetual maintenance, manholes settled. Roads repaved often. Surveyed periodically.
16	Depth: 20 ft Age: 8 years	park	residential, agricultural	steel, prefabricated building concrete pier	maintenance required	settlement of building, was raised, asphalt floor installed
17	Depth: 60 ft Age: 6 years	rubbish transfer station	pistol range	steel frame, reinforced concrete retaining walls	maintenance required	floor crack allows gas, odors to enter. Utility lines break occasionally. Odors and gases have given employees headaches
18	Depth: 10-30 ft Age: 8 years	park	industrial	buildings under construction spread footings on natural grade	under construction	none

TABLE I-2

SITE INVESTIGATIONS (Continued)

Site No.	Physical Characteristics of Site	Present Use	Adjacent Property Use	Types of Structures on Landfills	Physical Conditions of Improvements	Problems and Solutions
19	Depth: 20-60 ft	ball park, concession stand, rest rooms	pistol range, residential	frame and plywood; sheathing floating slab, spread footings	buildings look good	leaning light standards Some pavement separation at buildings due to settlement

TABLE I-3

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
1	40 acres 10-30 ft deep (swamp & pit)	50% garbage 35% rubbish 10% yard trimming 5% industrial	4	0.5	2	Industrial Vacant Commercial	None		3	Groundwater at 25 ft	Yes	Controlled by drainage, deodorant, and covering	Water pockets let gas escape
2	2 acres 50-60 ft deep pit	60% garbage 25% rubbish 10% yard trimming 4% industrial	No Response	No Response	No Response	Residential	Brick and wood frame on concrete slabs	10	No Response	No Response	None	No Response	
3	30 acres 16 ft deep (swamps)		2	0.5	2	Residential Industrial Vacant	Steel Frame and concrete block on piling	7	26	Offsite surface runoff, 25 acre drainage area	None	Negligible	
4	16 acres 12-15 ft deep (open area and swamps)	25% garbage 35% rubbish 28% industrial 5% construction and demolition debris 7% bulking refuse	3-4	1	2.5	Industrial Commercial	Steel Frame, reinforced concrete, concrete block: concrete slab, structure floating slab, piling	3-6	45	Offsite surface runoff, 1300 acre drainage area. There is a defined channel	None	Spray for fly control	Standard materials of construction in underground utilities
5	150 acres 16 ft deep (tidal area)	36% garbage 15% rubbish 48.5% construction and demolition debris	No Response	No Response	No Response	Vacant	Concrete block	12	55	Ground water at 10 ft.	None	Controlled by insecticides and rodenticides	Cast iron sewer lock joint pipe. Excavated 3 ft below, back filled and tamped to grade.

TABLE I-3 (Continued)

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
6	85 acres 5 ft deep (swamps and tidal areas)	40% garbage 24% rubbish 5% bulk refuse 2% street refuse 3% industrial 20% yard trimmings	5	0.75	No Response	Institutional	Concrete block, reinforced concrete, brick.	8	47	None	None	Rodent and pest control program	Special maintenance on structures. Periodic filling of ground near structures. Football field is settling.
7	63 acres 30 ft deep (level area and pit)	3% garbage 48% rubbish 13% yard trimmings 15% bulk refuse 20% construction and demolilition debris	6	0.5	2	Vacant Commercial (Airport)	Wood frame, steel frame, concrete block on concrete slab 14 inch pipeline	10	14.7	Snow disposed in winter offsite runoff (15 acres drainage area) additional 206 ft/yr applied in dry season ground water at 6 ft.	None	Controlled by Daily cover	Vertical movement has been recorded.
8	6 acres 14 ft deep (open area)	No Response	No Response	No Response	No Response	Residential Commercial	Concrete block on concrete slab. Sanitary sewers and water lines	6	16	Offsite runoff (120 acre drainage area)	No Response	No Response	Special maintenance of utilities and periodic leveling of structure
9	15 acres 8 ft deep (swamps, open area, and canyon)	25% garbage 60% rubbish 10% yard trimmings 5% industrial	6	0.5	2	Vacant	None	No Response	18-20	Offsite runoff (30 acre drainage area)	None	No Response	Operating under U. S. Public Health Grant, requested to contact U.S.P.H.S.

TABLE I-3 (Continued)

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
10	15 Acres 25 ft deep (swamps)	33% garbage 67% rubbish	1.5	0.5	2	Residential	Concrete block on piling	15	4	Groundwater at 5 ft, river backs up	None	Controlled by spraying and baiting	Special maintenance on structure - gas creeping into structure at openings for utilities
11	20 acres 6 ft deep (swamps)	0% garbage 50% rubbish 15% yard trimmings 10% bulk refuse 8% industrial 10% construction and demolition debris 7% other	No Response	No Response	No Response	Residential	None	No Response	33	Offsite runoff (5 acre drainage area)	None	None	Uneven settlement causes grass maintenance problems
12	40 acres 25-30 ft deep (swamps)	40% garbage 55% rubbish 5% yard trimmings	3-4	0.5	2-3	Institutional park	Concrete block on structural floating slabs sanitary sewers and water lines	2	27.8	None	None	No Problem	Concrete sanitary sewer lines, open trench
13	No Response (canyon)	sewage treatment residues (vacuum filter, 72% avg. moisture content)	6	0.75	2	Residential	Wood frame on structure floating slab, storm sewers	8	No Response	Groundwater at 45 ft	None	No Response	Storm sewer laid in non-sanitary fill
14	28 acres (level, pit and swamps)	No data	No Response	No Response	5'	Residential	Wood frame, reinforced concrete on piling and concrete slab, sewers, storm drains, and water lines	20	No Response	Groundwater at 8 ft	Yes	Very little odor	Driveways sink; all sewers, drains, gas lines are on piles

TABLE I-3 (Continued)

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
15	120 acres 25 ft deep (swamps)	75% garbage 3% rubbish 8% yard trimmings 2% bulk refuse 1% street refuse 1% industrial 10% construction and demolition debris	25	None	1	Vacant	Wood frame, with concrete slab or conventional foundation	2	50	None	None	None	Jack up floor slabs to relevel, special maintenance on structures
16	15 acres 8 ft deep (open area)	10% garbage 90% rubbish	1-2	0-0.5	1-2	Industrial	Steel frame, concrete block, conventional foundation	8	30	Ground water at 4 ft	Yes	None	Water pollution isolated instance
17	36 acres (canyon)	10% garbage	3	No Response	2	None	None	--	16	Offsite runoff (10 acre drainage area)	No Response	No Response	Vertical movement has been recorded.
18	22 acres 28-30 ft deep (open area and swamps)	5% garbage by volume soil mixed with rubbish in ratio of 1 to 4	3	No Response	2	None	None	--	15	None	No Response	No Response	Vertical movement has been recorded.
19	18 acres 22-113 ft deep (canyon)	47% household 12% industrial 8% lumber 4% garden wastes 23% solid fill 6% miscellaneous	15-20	0.75	2-3	None	None	--	16.5	None	No Response	No Response	Vertical movement has been recorded.

TABLE I-3 (Continued)

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
20	40 acres (canyon)	77% rubbish 23% street refuse	9	1	2	None	None	--	15	None	No Response	No Response	Vertical movement has been recorded
21	55 acres 110 ft deep (pit)	30% household 19% industrial 22% lumber 3% garden wastes 17% solid fill 9% miscellaneous	15-20	0.75	2-3	None	None	--	18	None	No Response	No Response	Vertical movement has been recorded
22	18 acres 35 ft deep (canyon)	50% garbage 5% yard trimmings 5% street refuse 26% industrial 14% construction and demolition debris	12	1	3	Residential	None	--	25	Offsite surface runoff	None	No Response	
23	10 acres 35 ft deep (pit)	50% garbage 5% hard trimings 5% street refuse 26% industrial 14% construction and demolition debris	12	1	3	Industrial	Brick on concrete slab or piling, sewers and storm drains	5	25	Offsite surface runoff (10 acre drainage area)	None	No Response	Storm drains and sewers per City code

TABLE I-3 (Continued)

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
24	53 acres 35 ft deep (swamps)	47% rubbish 6% yard trimmings 4% street refuse 6% industrial 36% construction and demolition debris	12	1	3	Industrial	Wood frame, steel frame, concrete block, reinforced concrete foundation: concrete slab piling structural floating slab, sanitary and storm drains, water lines	2	25	None	None	No Response	Tree planting problems - other responses indicate much utilization of land
25	20 acres 10 ft deep (canyon)	75% garbage and rubbish 15% yard trimmings 10% construction and demolition debris	No Response	No Response	1.5	Industrial Vacant	Wood frame on concrete slab	10	16	None	None	No problem	Special maintenance and periodic leveling of structures
26	25 acres 28 ft deep (pit)	25% garbage and rubbish 5% yard trimmings 10% bulky refuse 60% industrial	3	1	3	Residential Industrial Vacant Commercial	Wood frame on concrete slab	60	33	None	None	Disinfectant applied monthly	Kept above water table

TABLE I-3 (Continued)

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
27	15 acres 20 ft deep (tidal area)	50% garbage 40% rubbish 5% yard trimmings 3% bulky refuse 1% street refuse 1% construction and demolition debris	6	1	2	Bay waters	Wood frame on piling, sanitary sewers	3	30	Sea water	Tidal fill no problem	Gas production in garbage fill	Special maintenance on structures, tilted piles
28	80 acres 10 ft deep (swamp)	No Response	4	0.5	2	Commercial	Wood frame on concrete slab, sewers and water lines	0.5	31	None	None	Controlled by orthol disinfectant	
29	No Response (canyon)	10% yard trimmings 60% bulky refuse 15% street refuse 15% industrial 6 ton per day sewage treatment residues	No Response	1.5	3	Vacant	Wood frame, water lines	0.5	No Response	None	None	Shoot gulls and rodents and spray with chemicals	"Use plenty of equipment and manpower"
30	30 acres 15ft deep (open area)	50% garbage 25% rubbish 10% yard trimmings 10% bulk refuse 20% street refuse 5% industrial 5% construction and demolition debris	5	3	3	Residential Industrial Vacant	Concrete block on piling	5	40	None	None	No Response	Special maintenance and periodic leveling

TABLE I-3 (Continued)

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
31	10 acres (swamps)	40% garbage 40% rubbish 10% yard trimmings 10% street refuse	No Response	No Response	No Response	Industrial	Brick on concrete slab, sewers and storm drains	5	56	No Response	None	No Response	"Get good compaction"
32	8 acres 10 ft deep (swamps)	95% garbage 5% yard trimmings	6	0.5	2	Residential	Wood frame on concrete slabs, sewers and water lines	2	56	Groundwater at 8 ft	None	None	Pipe laying excavation creates odors
33	140 acres 15 ft deep (open area)	25% garbage 10% rubbish 10% industrial 50% construction and demolition debris 4.5% sewage treatment residues 75% avg. moisture	1	1	No Response	Industrial Commercial Water	Wood frame, concrete block, on concrete slabs and structural floating slab	6	No Response	Groundwater at 3 ft	None	None	"Follow landfill planning"
34	No Response (open area and swamps)	100% garbage	4	No Response	2	Residential	Brick	6	No Response	None	No Response	No Response	

TABLE I-3 (Continued)

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
35	500 acres 90 ft deep to max of 300-500 ft	36% household rubbish 22% fibrous and woody 37% solid fill 3% miscellaneous	15-20	0.75	2-3	No Response	No Response	No Response	15	Reported to be none	No Response	No Response	No Response
36	15 acres 60 ft deep (pit)	Residential garbage and rubbish	13-15	One	2	Pistol range, Residential	Reinforced concrete, conventional concrete slab, water and sewer lines, sub-connections on water lines	Constructed immediately after completion of landfill	14				Jacking, filling with blocks and grout, broken sewers and water lines, gas movement evidenced in fill, shallow trench and burners installed to vent gases.
37	16 ft deep some depths to 66 ft	68% organic garbage 21% paper 2% glass and plastic 3% rags and bones 4% metal and ceramics 3% wood, leather and rubber	3	1.5		University, light and heavy industry, warehouses, slum housing	Water tank on 8 piles, 2 at each of 4 corners, sewer, water and electric utilities in One story buildings sanitation dept. shops and offices. Stone paved road 400 trucks/day @ 20 ton/truck	Water tank on fill, 25 years				Smoke from spontaneous combustion blows into industrial and residential areas.	Buzzards fly into paths of and collide with aircraft. Mud flows into nearby channel. Tilted water tank. Corrosion of gas lines causes leakage.

TABLE I-3 (Continued)

RESPONSE TO LONG-FORM QUESTIONNAIRE

Area No.	Size of Fill	Type of Fill	Daily Refuse Lift (ft)	Daily Earth Cover (ft)	Final Earth Cover (ft)	Adjacent Property Use	Type of Structures on Fill	Age When Structures Were Built (years)	Annual Rainfall (inches)	Other Water Sources	Groundwater Sources	Odor and Nuisance Problems	Other Problems or Solutions
38	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response	No Response	Seagulls are a hazard to aircraft	Response was a 136 page booklet of indigenous recommendations.
39	25 acres 28 ft below water table	Garbage brush and garden refuse 70,000 ton/ year				Residential	Light poles, fences, baseball backstop, clubhouse, observation tower, pavement.			Water table above bottom of fill.		H_2S due to decomposition of organics under the water.	Fill contoured surface; sodium nitrate reduced H_2S from 5 ppm to 0 ppm in one week. DO then was 4 ppm. "Cheaper than aeration".
40	19 acres 20 to 30 ft. Cells of 20-30 ft diameter						105 subdivision lots 38% of roads traverse fill, sanitary landfill cells and 63 lots on cells.			Groundwater 4'-12' below surface.		Toxic, flammable gases.	Settlement - major program recommended in 12 page report for surface and subsurface reconstruction, venting and seeding.
41	16-18 ft deep, 35 ft deep at one end.					Recreation area.	300 x 400 ft building with concrete slab, water, gas, sewers in ground. Electrical on surface. Asphalt pavement, Incineration.						Fire from gases ignited, passing through cracks in the slab. Vent installed later (Building) Settlement at incinerator

TABLE II-1

SETTLEMENT RECORD AT SITE 2-B

Monument	Depth of Fill (ft)	Elevations 5/22/67	12/11/67	6/10/68	12/02/68	5/14/69	10/23/69	Settlement (ft)	Lateral Movement (ft) North	East
CL 1	24	1078.80	1078.80	1078.80	1078.80	1078.80	1078.80	0.00	0.01	0.00
CL 2	104	1139.07	1138.71	1138.46	1138.23	1137.98	1137.82	1.25	0.16	0.33
CL 3	92	1141.53	1141.21	1140.98	1140.77	1140.55	1140.45	1.08	0.20	0.36
CL 4	73	1143.32	1143.05	1142.85	1142.67	1142.49	1142.43	0.89	0.20	0.27
CL 5	78	1143.98	1143.70	1143.51	1143.33	1143.15	1143.08	0.90	0.19	0.23
CL 6	112	1145.88	1145.55	1145.30	1145.09	1144.89	1144.78	1.10	0.13	0.22
CL 7	113	1145.97	1145.57	1145.29	1145.03	1144.80	1144.66	1.31	-0.03	0.20
CL 8	104	1147.05	1146.68	1146.40	1146.16	1145.87	1145.71	1.34	0.04	0.20
CL 9*	-	1180.01	-	-	-	-	-	0.00	0.00	-0.02
CL 10	54	1138.24	1138.01	1137.85	1137.70	1137.51	1137.44	0.80	0.07	0.24
CL 11	22	1134.76	1134.66	1134.59	1134.51	1134.41	1134.39	0.37	-0.09	0.05
CL 12	53	1131.15	1131.02	1130.93	1130.82	1130.67	1130.61	0.54	-0.06	0.11
CL 13	-	1128.81	1128.75	1128.71	1128.65	1128.60	1128.55	0.26	-0.01	0.00
CL 14*	-	1126.98	1126.98	1126.98	1126.98	1126.98	1126.98	0.00	-0.01	-0.03

* Control monuments on ground adjacent to fill.

TABLE II-2

SETTLEMENT RECORD AT SITE 3

Station	Depth of Fill (ft)	Elevations						Change in Elevation (ft)	
		8/03/67	1/29/68	6/12/58	12/03/68	5/19/69	10/22/69	+	-
Line A:									
1+00	-	29.37	29.26	Lost	Lost	Lost	Lost		0.11
2+00	-	30.23	30.13	Lost	Lost	Lost	Lost		0.10
2+00 Grnd.	-	-	-	28.4	28.5	28.4	-	0.0	0.0
2+57.3	-	-	-	-	29.50	29.5	29.47		0.03
3+00	29	29.54	29.55	29.54	29.47	29.35	29.34		0.20
4+00	29	29.42	29.36	29.34	29.27	29.24	29.20		0.22
5+00	29	29.78	29.69	29.63	29.52	29.46	29.40		0.38
5+61	30.5	31.04	31.05	31.03	30.97	30.95	30.93		0.11
5+86.7	-	30.7	30.8	30.7	30.7	30.7	30.7	0.0	0.0
6+00	-	30.5	30.5	30.5	30.5	30.5	30.5	0.0	0.0
7+00	-	30.0	29.9	30.0	30.3	30.2	30.2	0.2	
7+90.6	-	30.1	30.1	30.0	30.1	30.0	30.1	0.0	0.0
8+00	29.5	30.0	30.0	30.0	30.1	30.0	30.1	0.1	
9+00	29	29.6	29.7	-	29.9	29.5	29.7	0.1	
10+01.	29	29.31	39.30	29.27	29.19	29.14	29.12		0.19
Line B:									
1+00	-	28.17	28.22	28.16	28.13	28.12	28.13		0.04
1+75	-	-	-	29.51	29.50	29.46	29.47		0.04
2+00	29	29.24	29.20	29.40	29.36	29.31	29.28		0.12
2+19	-	-	-	29.6	29.55	29.4	29.37		0.23
2+82	-	-	-	30.0	30.01	30.0	29.94		0.06
3+00	28.5	29.96	29.92	30.05	30.02	29.96	29.94		0.11

TABLE II-2 (Continued)

SETTLEMENT RECORD AT SITE 3

Station	Depth of Fill (ft)	Elevations 8/03/67	1/29/68	6/12/68	12/03/68	5/19/69	10/22/69	Change in Elevation (ft) +	-
Line B									
3+44.4	-	-	-	30.1	30.06	30.0	29.90		0.20
3+51.5	-	30.13	30.03	Lost	Lost	Lost	Lost		0.10
3+51.8	-	-	-	30.0	29.85	29.8	29.70		0.30
4+00	29.7	30.15	30.14	30.08	30.05	30.03	29.97		0.18
4+39.4	-	-	-	-	30.72	30.67	30.65		0.07
4+54	30	30.76	30.70	Lost	Lost	Lost	Lost		0.06
4+64.7	-	-	-	30.77	30.72	30.65	30.62		0.15
5+00	30	30.4	30.7	30.0	30.5	30.5	30.4	-	-
6+00	30	30.3	30.2	30.2	30.3	30.2	30.3	-	-
7+00	29	29.6	29.6	29.6	29.7	29.6	29.7	0.1	
8+00	29	29.1	29.0	29.0	28.9	28.7	28.7		0.4
8+14.8	28	28.59	28.32	28.20	28.05	27.89	27.71		0.78
Floor-H.T. DR	-	30.28	30.13	29.94	29.83	29.63	29.43		0.85
Floor-V.T. DR	-	30.39	30.27	30.18	30.05	29.92	29.81		0.58
Floor-Off. DR	-	30.83	30.81	-	-	-	-		0.02
Floor-L. Rm.	-	30.86	30.85	30.75	30.70	30.69	30.65		0.21
Floor-M-RR	-	-	-	30.70	30.65	30.57	30.53		0.17
Floor-S.B.	-	30.86	30.76	30.59	-	30.46	30.31		0.55
Slab S.B. NW	-	30.85	30.80	30.69	30.64	30.58	-		0.27
Slab S.B. NE	-	30.51	30.34	30.49	30.38	30.25	30.16		0.35

TABLE II-3

SETTLEMENT RECORD AT SITE 5

Monument	Elevations 4/27/65	6/30/67	1/30/68	6/13/68	12/04/68	5/19/69	10/24/69	Settle-ment (ft)	Lateral Movement (ft) North	East
Comfort Stations:										
North Station:				9/03/68						
S. Corner				375.60	375.52	375.36	375.26	0.34		
W. Corner				375.55	375.47	375.27	375.16	0.39		
South Station:										
NW Corner				416.63	416.57	416.42	416.38	0.25		
SW Corner				416.62	416.56	416.41	416.36	0.26		
6 FT N of SW Cr.				416.61	416.54	416.40	-	0.21		
SE Corner				416.63	416.56	416.38	416.32	0.31		
NE Corner				416.59	416.54	416.35	416.29	0.30		

Monument	Depth of Fill (ft)	Elevations 4/4/64	10/28/66	12/04/68	5/19/69	10/24/69	Settlement (ft) Since 4/4/64
101	80	382.37	381.85	381.53	381.41	381.38	0.99
103	100	382.36	381.63	380.92	376.11	-	6.25
104	90	387.57	387.28	386.98	386.99	386.82	0.75
105	95	382.46	381.76	381.34	381.29	381.19	1.27
106	120	287.91	386.60	385.78	385.64	385.48	2.43
107	130	390.08	387.02	388.32	388.23	388.12	1.96
108	130	386.64	385.77	385.15	385.05	384.89	1.75
109	95	382.20	381.31	380.86	380.72	380.58	1.62

TABLE II-3 (Continued)

SETTLEMENT RECORD AT SITE 5

Monument	Depth of Fill (ft)	Elevations					Settlement (ft) Since 4/4/64
		4/4/64	10/28/66	12/04/68	5/19/69	10/24/69	
110	95	375.53	374.46	373.97	373.89	373.80	1.73
111	115	387.28	386.55	386.17	386.12	386.06	1.22
112	125	393.86	392.64	391.97	391.86	391.75	2.11
113	120	392.69	392.06	391.80	391.77	391.75	0.94
114	95	378.26	377.54	376.91	376.72	-	1.54
116	90	388.86	386.99	386.13	386.04	386.00	2.86
117	90	386.00	384.13	383.47	383.36	382.32	2.68
118	75	370.10	367.85	367.16	387.03	-	3.07
120	85	374.10	371.98	371.10	371.00	-	3.10
121	46	356.81	355.55	355.12	355.05	-	1.76

TABLE II-3 (Continued)

SETTLEMENT RECORD AT SITE 5

	Elevations							Settle-ment	Lateral Movement (ft)	
Monument	4/27/65	6/30/67	1/30/68	6/13/68	12/04/68	5/19/69	10/24/69	(ft)	North	East
Line A										
N3000/E2900		406.19	406.12	406.77	406.75	406.50	406.46	+0.27		
N3000/E3000	388.89	388.54	388.50	388.47	388.49	388.37	388.31	0.58		
N3000/E3100		372.65	372.62	372.61	372.66	372.51	372.43	0.22		
N3000/E3200		351.13	351.13	351.10	351.18	350.97	350.90	0.23		
N3000/E3300		343.17	343.17	343.15	343.22	343.23	-	+0.06		
N3000/E3400		355.89	355.49	355.47	355.53	355.53	355.48	0.41		
N3000/E3500	361.39	361.33	361.33	361.27	361.30	361.29	361.21	0.18		
N3000/E3600		369.96	369.88	369.83	369.80	369.73	369.62	0.34		
N3000/E3700		371.77	371.71	371.67	371.65	371.58	371.52	0.25		
N3000/E3800		378.89	378.83	378.75	378.76	378.66	378.59	0.30		
N3000/E3900		384.27	384.13	384.07	384.01	383.90	383.80	0.47		
N3000/E4100		384.06	384.00	383.94	383.87	383.79	383.68	0.38		
N3000/E4200		384.07	383.98	383.90	383.89	383.79	383.70	0.37		
N3000/E4300		364.68	364.40	364.25	364.11	363.79	363.43	1.25		
N3000/E4382.89		344.09	-	344.08	344.10	344.12	344.08	0.01		
Line B:										
N3500/E2016		409.82	409.80	409.81	-	409.82	409.81	0.01		
N3500/E2121		409.39	409.34	409.39	409.33	409.33	409.32	0.07		
N3500/E2306		408.86	408.82	408.87	408.81	408.86	408.86	0.00		
N3500/E2500		410.84	410.83	410.85	410.81	410.85	410.85	+0.01		
N3500/E2666		408.55	408.48	408.52	408.42	408.43	408.42	0.13		
N3500/E2815		399.40	399.30	399.32	399.23	399.15	399.06	0.34		

TABLE II-3 (Continued)

SETTLEMENT RECORD AT SITE 5

Monument	Elevations							Settle-ment (ft)	Lateral Movement (ft)	
	4/27/65	6/30/67	1/30/68	6/13/68	12/04/68	5/19/69	10/24/69		North	East
Line B										
N3500/E3000		387.50	387.33	387.29	387.16	386.96	386.87	0.63		
N3500/E3120		380.31	380.16	380.14	380.05	379.94	379.90	0.41		
N3500/E3257		343.23	343.00	342.98	-	-	-	0.25		
N3500/E3317		-	327.29	327.21	-	-	-	0.08		
N3500/E3361		-	325.85	325.66	325.41	-	-	0.44		
N3500/E3447		345.73	345.21	344.87	344.38	343.52	342.57	3.16		
N3500/E3500	357.51	355.97	355.64	355.45	355.10	354.52	353.84	3.67		
N3500/E3600		371.01	370.81	370.71	370.53	370.40	370.17	0.84		
N3500/E3700		379.51	379.29	379.20	379.04	378.90	378.69	0.82		
N3500/E3800		386.94	386.70	386.61	386.45	386.34	386.19	0.75		
N3500/E3900		391.24	391.04	390.96	390.82	390.73	390.60	0.64		
N3500/E4100		392.81	392.58	392.45	392.33	392.17	392.03	0.78		
N3500/E4200		390.89	390.65	390.52	390.37	390.26	390.18	0.71		
N3500/E4300		386.57	386.41	-	386.23	386.17	386.05	0.52		
N3500/E4400		382.53	382.39	382.30	382.14	381.90	381.79	0.74		
N3500/E4500		372.79	372.72	372.70	372.64	372.56	372.56	0.23		
N3500/E4600		342.39	342.38	-	342.40	342.39	342.41	+0.02		
N3500/E4635		333.58	333.57	333.57	333.58	333.57	333.61	+0.03		
Comfort Stations:										
North Station:				9/03/68						
N. Corner				375.47	375.38	375.13	-	0.34		
6 Ft SE of N Cor.				375.47	375.40	375.15	375.01	0.46		
E. Corner				375.49	375.41	375.19	375.07	0.42		

TABLE II-3 (Continued)

SETTLEMENT RECORD AT SITE 5

Monument	Elevations							Settlement (ft)	Lateral Movement (ft)	
	4/27/65	6/30/67	1/30/68	6/13/68	12/04/68	5/19/69	10/24/69		North	East
Base line:										
N4300/E4000	-	378.31	-	-	378.31	378.32	378.32	+0.01		
N4100/E4000		360.18	360.08	360.04	-	-	-	0.14		
N4095/E4000		360.35	360.23	360.20	360.13	360.09	360.03	0.32	-0.09	-0.13
N4000/E4000	364.02	362.86	362.47	362.35	362.21	361.91	361.76	2.26	-0.54	-0.26
N3900/E4000		374.42	374.18	374.12	374.02	-	-	0.40	-0.11	-0.69
N3800/E4000		385.49	385.37	385.35	385.31	385.26	385.22	0.27		
N3700/E4000		390.20	390.04	390.01	389.93	389.86	389.78	0.42		
N3600/E4000		392.21	392.07	392.03	391.93	391.90	-	0.31	-0.28	-0.22
N3500/E4000		393.03	392.82	392.72	392.58	392.46	392.34	0.69	0.08	0.00
N3400/E4000		393.24	393.17	393.11	393.01	392.96	392.86	0.38		
N3300/E4000		390.20	390.08	390.02	389.94	389.92	389.84	0.36	-0.06	-0.17
N3200/E4000		384.21	383.98	383.88	383.74	383.61	383.48	0.73		
N3100/E4000		380.41	380.22	380.12	380.01	379.92	379.82	0.59		
N3000/E4000	381.58	380.83	380.69	380.61	380.56	380.47	380.39	1.19	-0.07	-0.05
N2900/E4000		386.03	385.93	385.92	385.85	385.82	385.78	0.25		
N2800/E4000		388.27	388.21	388.18	388.14	-	-	0.13		
N2773.60/E4000		387.76	387.67	387.66	387.61	387.59	387.54	0.21	0.00	0.00
N2700/E4000		385.85	385.63	385.71	385.66	385.60	385.54	0.31		
N2600/E4000		386.31	386.16	386.12	386.02	385.92	385.80	0.51		
Line A:										
N3000/E2600		412.94	411.51	411.51	411.52	411.50	411.50	1.44		
N3000/E2700		408.93	-	408.84	408.93	408.77	-	0.16		

TABLE II-4

SETTLEMENT AND LATERAL MOVEMENT RECORD AT SITE 7

Monument Designation, Date Established	Depth of Fill (ft)	* Settlement (ft)	Lateral Movement (ft)	
			Easterly	Northerly
"Sterns" (Oct. 1964)	285	22.81	1.774	-1.738
"L" (Aug. 1960)	70	7.96	2.19	0.77
"SN" (Dec. 1963)	280	30.51**	Not Available	

* As of June 1969.

** Stockpiling of clear earth cover material adjacent to bench mark commenced in Jan. 1965 and is now approximately 40 feet deep, 150 feet wide, and 700 feet long.

TABLE II-5

SETTLEMENT RECORD AT SITE 9

Monument Designation East	North	9/66	9/67	9/68	9/69	Settlement (ft)
0+00	0+00	380.8	378.2	377.0	377.6	3.2
	1+00	380.6	378.7	378.2	378.7	1.9
	2+00	380.4	379.1	378.9	378.1	2.3
	3+00	380.2	378.6	378.5	378.4	1.8
	4+00	380.0	377.8	377.4	378.2	1.8
	5+00	379.8	379.2	379.2	378.9	0.9
	6+00	379.6	379.0	379.1	378.2	1.4
	7+00	379.4	379.4	-	378.5	0.9
1+00	0+00	381.0	377.6	377.5	377.5	3.5
	1+00	380.8	378.7	377.8	375.9	4.9
	2+00	380.6	378.2	377.0	374.4	6.2
	3+00	380.4	378.3	377.4	375.9	4.5
	4+00	380.2	378.0	377.2	376.2	4.0
	5+00	380.0	378.0	377.4	376.5	3.5
	6+00	379.8	378.4	377.9	377.3	2.5
	7+00	379.6	377.7	376.8	375.8	3.8
	8+00	379.4	378.0	376.4	375.3	4.1
	8+88	-	378.4	377.5	377.6	0.8
2+00	0+00	381.2	378.0	377.9	378.0	3.2
	1+00	381.0	378.6	377.0	375.6	5.4
	2+00	380.8	378.5	377.2	374.6	6.2
	3+00	380.6	378.4	377.4	375.1	5.5
	4+00	380.4	378.1	377.0	375.3	5.1

TABLE II-5 (Continued)

SETTLEMENT RECORD AT SITE 9

Monument Designation East	North	9/66	9/67	9/68	9/69	Settlement (ft)
2+00						
	5+00	380.2	378.4	377.5	376.6	3.6
	6+00	380.0	379.2	378.1	377.1	2.9
	7+00	379.8	378.1	376.9	376.1	3.7
	8+00	379.6	378.1	376.5	375.4	4.2
	8+83	-	378.6	377.2	376.9	1.7
3+00	1+00	381.2	379.7	378.9	377.5	3.7
	2+00	381.0	379.3	378.5	377.0	4.0
	3+00	380.8	378.8	377.6	375.5	5.3
	4+00	380.6	378.3	377.6	375.7	4.9
	5+00	380.4	378.9	377.7	376.4	4.0
	6+00	380.2	378.8	378.1	377.3	2.9
	7+00	380.0	378.4	377.4	376.8	3.2
	8+00	379.8	378.2	376.9	376.0	3.8
	8+85	-	378.7	378.1	377.3	1.4
4+00	1+00	381.4	381.3	381.0	380.8	0.6
	2+00	381.2	380.8	380.5	380.1	1.1
	3+00	381.0	379.4	378.5	377.3	3.7
	4+00	380.8	379.0	378.1	376.9	3.9
	5+00	380.6	378.7	377.8	376.7	3.9
	6+00	380.4	378.2	376.7	375.2	5.2
	7+00	380.2	379.3	376.5	375.7	4.5
	8+00	380.0	379.1	378.4	378.0	2.0
	8+78	-	378.5	378.5	378.1	0.4

TABLE II-5 (Continued)

SETTLEMENT RECORD AT SITE 9

Monument Designation East	North	9/66	9/67	9/68	9/69	Settlement (ft)
4+47	1+00	-	382.0	382.1	381.8	0.2
	2+00	381.3	381.6	381.4	381.1	0.2
	3+00	381.1	380.3	379.4	378.2	2.9
	4+00	380.9	379.8	379.2	378.4	2.5
	5+00	380.7	379.8	379.0	378.1	2.6
	6+00	380.5	379.0	376.8	375.0	5.5
	7+00	380.3	379.1	378.1	377.4	2.9
	8+00	-	379.7	379.6	-	0.1
5+00	2+07	384.1	383.5	383.0	382.6	1.5
	3+00	385.0	383.0	382.1	383.1	1.9
	4+00	386.0	383.9	383.3	382.3	3.7
	5+00	387.0	385.0	384.4	383.2	3.8
	6+00	388.0	385.9	383.9	382.6	5.4
	6+73	388.9	386.9	386.3	-	2.6
6+00	2+23	385.2	384.5	384.7	383.5	1.7
	3+00	386.0	383.8	382.9	381.4	4.6
	4+00	387.0	384.8	384.1	382.6	4.4
	5+00	388.0	386.0	385.1	383.9	4.1
	6+00	389.0	387.3	386.4	385.5	3.5
	6+51	389.6	387.8	387.3	386.6	3.0
7+00	2+36	386.4	385.7	385.4	384.8	1.6
	3+00	387.0	385.1	384.3	383.6	3.4
	4+00	388.0	386.3	385.6	384.4	3.6

TABLE II-5 (Continued)

SETTLEMENT RECORD AT SITE 9

Monument Designation East	North	9/66	9/67	9/68	9/69	Settlement (ft)
7+00						
	5+00	389.0	387.1	386.7	385.5	3.5
	6+00	390.0	388.3	387.7	387.0	3.0
	6+47	390.6	388.9	388.4	387.9	2.7
8+00	2+52	387.5	386.6	385.9	385.6	1.9
	3+00	388.0	386.8	386.1	385.4	2.6
	4+00	389.0	387.7	387.1	386.0	3.0
	5+00	390.0	388.6	388.0	387.1	2.9
	6+00	391.0	389.2	388.8	388.0	3.0
	6+50	391.6	390.2	390.0	389.6	2.0
9+00	2+68	388.7	387.6	387.5	387.3	1.4
	3+00	389.0	388.0	387.6	387.0	2.0
	4+00	390.0	389.1	388.6	387.7	2.3
	5+00	391.0	389.9	389.4	388.6	2.4
	6+00	392.0	390.2	389.9	389.2	2.8
	6+60	392.7	390.9	391.4	390.8	1.9
9+48	6+00	392.5	391.0	390.0	390.2	2.3
9+57	5+00	391.6	390.7	390.6	389.9	1.7
9+64	4+00	390.6	389.9	389.4	388.9	1.7

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TABLE II-6

SETTLEMENT RECORD AT SITE 10

Survey Pt.	Settlement (ft)
1	5.4
2	0.8
3	5.7
4	3.9
5	1.8
6	3.6
7	3.9
8	2.8
9	0.6
10	2.8
11	1.0
12	5.3

TABLE II-7

SETTLEMENT RECORD AT SITE 11

Monument	Depth of Fill (ft)	Elevations			Settlement (ft)
		12/7/64	12/11/68	5/20/69	
100 Series Monuments					
101	25	1328.07	1328.10	1328.11	(On inert fill)
102	60	1330.52	1329.84	1329.74	0.78
103	55	1332.75	1332.07	1331.96	0.79
104	75	1336.25	1335.44	1335.26	0.99
105	60	1339.76	1339.19	1339.13	0.63
106	125	1343.59	1341.82	1341.60	1.99
107	25	1329.67	1329.69	1329.74	(On inert fill)
108	65	1331.66	1330.31	1330.15	1.51
109	95	1335.30	1332.41	1332.09	3.21
110	115	1338.07	1334.34	1333.80	4.27
111	150	1341.39	1338.24	1337.89	3.50
112	175	1344.89	1339.25	1338.66	6.23
113	100	1339.55	1331.42	1330.66	8.89
114	100	1343.21	1334.11	1333.32	9.89
		7/15/65			
300 Series Monuments					
301	140	1358.85	1355.73	1355.50	3.35
302	155	1363.95	1358.97	1358.37	5.58
303	90	1368.98	1366.26	1365.95	3.03
304	70	1374.04	1373.30	1373.31	0.73
305	55	1359.88	1357.97	1357.87	2.01

TABLE II-7 (Continued)

SETTLEMENT RECORD AT SITE 11

Monument	Depth of Fill (ft)	Elevations			Settlement (ft)
		7/15/65	12/11/68	5/20/69	
300 Series Monuments					
306	160	1372.48	1368.66	1368.31	4.17
307	100	1377.92	1375.25	1375.10	2.82
308	40	138169	1381.16	1381.18	0.51
309	30	1357.65	1357.24	1357.19	0.46
310	135	1369.56	1366.01	1365.56	4.00
311	50	1380.79	1379.36	1379.19	1.60
312	25	1358.92	1358.86	1358.88	0.04
313	105	1366.58	1362.77	1362.54	4.04
314	70	1373.25	1371.77	1371.69	1.56
315	40	1366.77	1365.94	1365.87	0.90

TABLE II-8

SITE 5: SETTLEMENT/DEPTH-OF-FILL

Monument	Fill Depth (ft)	Years Elapsed	Cumulative Settlement (ft)	Percentage Settlement/Depth
105	95	5.5	1.27	1.34
106	120	5.5	2.43	2.02
107	130	5.5	1.96	1.51
112	125	5.5	2.11	1.69
116	90	5.5	2.86	3.18
118	75	5	3.07	4.1
120	85	5	3.10	3.64

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TABLE II-9

SITE 11; AREA 1: SETTLEMENT/DEPTH-OF-FILL

Monument	Fill Depth	Years Elapsed	Cumulative Settlement	Percentage Settlement/Depth
109	95	4.4	3.21	3.38
110	115	4.4	4.27	3.71
111	150	4.4	3.50	2.33
112	175	4.4	6.23	3.56
113	100	4.4	8.89	8.89
114	100	4.4	9.89	9.89

TABLE II-10

SITE 11, AREA 3: SETTLEMENT/DEPTH-OF-FILL

Monument	Fill Depth	Years Elapsed	Cumulative Settlement	Percentage Settlement/Depth
301	140	3.8	3.35	2.39
302	155	3.8	5.58	3.77
303	90	3.8	3.03	3.40
304	70	3.8	.73	1.04
305	55	3.8	2.01	3.66
306	160	3.8	4.17	2.61
307	100	3.8	2.82	2.82
308	40	3.8	.51	1.28
309	30	3.8	.46	1.53
310	135	3.8	4.00	2.96
311	50	3.8	1.60	3.20
312	25	3.8	.04	1.6
313	105	3.8	4.04	3.86
314	70	3.8	1.56	2.22
315	40	3.8	0.90	2.25

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TABLE II-11

DEPTH-OF-FILL COMPARISONS WITH PERCENTAGES: SETTLEMENT/DEPTH

	Percentage:	Settlement/Depth (Approximate)	
Depth of Fill	Site 5	Site 11, Area 1	Site 11, Area 3
25			1.6
30			1.5
40			2.3
50			3.2
55			3.7
70			2.2
75	4.1		
85	3.6		
90	3.2		3.4
95	1.3	3.4	
100		9.10	2.8
105			3.9
115		3.7	
120	2.0		
125	1.7		
130	1.5		
135			3.0
140			2.4
150		2.3	
155			3.8
160			2.6
175		3.6	

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TABLE II-12

COMPOSITION AND ANALYSIS OF EXPERIMENTAL REFUSE MIXTURES

Component	Analysis By Weight		Weight Percent in Mixture		
	% Water	% V_m	High Paper	Medium Paper	Low Paper
Paper	1.16	>99.3	60	30	20
Garbage	96.20	75.3	10	20	30
Garden Waste	22.6	83.5	10	20	20
Metal, Glass, Ceramics	~0	~0	10	20	20
Rags, Plastics, Leather	1.04	>99.0	5	5	5
Inert Soil	~0	~0	5	5	5
Calculated % water in refuse			12.63	24.16	33.66
Calculated % V_m refuse solids			80.70	63.2	57.70

TABLE II-13

ESTIMATED CARBON AND NITROGEN CONTENT OF EXPERIMENTAL REFUSE MIXTURES

Component	Composition[1]			Weight Percent in Mixture		
	% C	% N	C/N	High Paper	Medium Paper	Low Paper
Paper	43.9	0.103	426	60	30	20
Garbage	41.5	1.92	21.6	10	20	30
Garden Waste	39.1	2.44	16.1	10	20	20
% Carbon				33.6	25.7	22.9
% Nitrogen				0.4	0.7	0.9
C/N ratio				90.8	35.0	24.6

NOTES: [1] Reference 25 (dry weight basis).

[2] Calculated on dry weight basis.

TABLE II-14

EFFECT OF COMPACTION EFFORT ON DRY REFUSE CELLS

Refuse Size	Fine			Mixed			Coarse		
Paper Content, %	20	30	60	20	30	60	20	30	60
Initial Refuse Height, h_o inches	5	5	5	5	5	5	5	5	5
Refuse Weight, lb	2.69	3.25	3.375	1.56	1.50	2.38	1.13	1.25	1.25
Initial Unit Weight, lb/ft^3	18.70	22.6	23.5	10.86	10.40	16.50	7.80	8.68	8.68
Height after n drops									
h_1	3.3	3.80	4.4	2.5	2.6	3.6	1.9	2.6	2.6
h_2	3.10	3.50	4.15	2.0	2.3	3.35	1.4	2.2	2.25
h_3	2.80	3.30	4.10	1.9	2.1	3.25	1.45	2.1	2.2
h_4	2.60	3.20	4.00	1.8	2.0	3.1	1.4	2.0	2.1
h_5	2.5	3.1	4.0	1.7	2.0	3.0	1.4	1.8	2.1
h_6	2.4	3.1	-	1.7	-	3.0	-	-	-
h_7, h_8	2.3	-	-	-	-	-	-	-	-

TABLE II-15

EFFECT OF WATER ADDITION ON REFUSE UNIT WEIGHT

Refuse Size	Fine						Mixed			Coarse		
Paper Content, %	20			30			30			30		
Water Added, % Saturation	25	50	75	25	50	75	25	50	75	25	50	75
% Dry Weight	12	24	36	17.6	35.2	53.0	28.2	56.4	84.6	34	68	102
Initial Refuse Height, inches	5	5	5	5	5	5	5	5	5	5	5	5
Weight of Dry Refuse, lb	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	1.67	1.67	1.67
Weight of Compacted Wet Refuse, lb	3.31	3.69	3.94	3.38	3.56	3.88	2.5	3.125	3.562	2.19	2.69	2.69
Water Content after Compaction,												
% Dry Weight	11.2	23.0	31.4	12.65	18.65	29.3	25.0	56.3	78.2	31.2	61.0	61.0
% Saturation	24.0	48.0	65.0	18.0	26.00	41.0	22.5	50.0	69.0	23.0	45.0	45.0
Equilibrium Characteristics of Refuse Cells[1]												
Refuse Height	2.7	2.7	2.8	2.8	2.6	2.7	2.0	2.1	2.2	1.5	1.6	1.6
Dry Unit Weight, lb/ft^3	38.7	38.7	37.3	37.4	40.2	38.7	34.8	33.2	31.7	38.7	36.3	36.3
Wet Unit Weight, lb/ft^3	42.8	47.7	48.8	42.2	47.5	50.0	43.8	52.0	56.5	51.0	58.5	58.5

NOTE: [1] After six drops of free falling weight on refuse mixtures.

TABLE II-16

POROSITY, VOIDS RATIO, AND UNIT WEIGHT OF DRY COMPACTED REFUSE

Refuse Size and Paper Content	Weight lb	Gross Volume 10^{-3} ft^3	Solids Volume 10-3 ft^3	Voids Volume 10^{-3} ft^3	Porosity %	Voids Ratio %	Gross Unit Weight lb/ft^3	Solids Unit Weight lb/ft^3
Fine - 20%	2.69	66.2	45.4	20.8	31.4	45.8	40.6	59.3
30%	3.25	89.4	52.6	36.8	41.2	70.0	36.4	61.8
60%	3.38	115.1	57 6	57.5	50.0	99.8	29.3	58.7
Mixed- 20%	1.56	49.0	25.25	23.7	48.4	94.0	31.9	61.7
30%	1.56	57.3	26.70	30.6	53.4	114.6	26.2	56.2
60%	2.38	86.1	38.80	47.3	55.0	122.0	27.6	61.4
Coarse-20%	1.13	40.3	17.65	22.6	56.1	128.0	28.1	64.0
30%	1.25	51.5	24.55	27.0	52.4	110.0	24.2	51.0
60%	1.25	60.3	18.73	41.6	69.0	222.0	20.7	66.6

TABLE II-17

SUBSIDENCE DURING AEROBIC DECOMPOSITION

Sample Code	F-20-0			F-30-0			F-60-0			M-20-0			M-30-0			M-60-0		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
0	0	12.75	44.3	0	10.81	37.6	0	8.69	30.2	0	10.69	37.1	0	9.69	33.6	0	7.56	26.2
1		12.75	44.3	0	10.81	37.6	0	8.69	30.2	0	10.69	37.1	0	9.69	33.6	0	7.56	26.2
2		12.75	44.3	0	10.81	37.6	0	8.69	30.2	0	10.69	37.1	0	9.69	33.6	0	7.56	26.2
3		12.75	44.3	0	10.81	37.6	0	8.69	30.2	0	10.69	37.1	0	9.69	33.6	0	7.56	26.2
4		12.75	44.3	0	10.81	37.6	0	8.69	30.2	0	10.69	37.1	0	9.69	33.6	0	7.56	26.2
5		12.75	44.3	0	10.81	37.6	0	8.69	30.2	0	10.69	37.1	0	9.69	33.6	0	7.56	26.2
6		12.75	44.3	0	10.81	37.6	0	8.69	30.2	0	10.69	37.1	0	9.69	33.6	0	7.56	26.2
10	2.0	12.75	45.2	0	10.81	37.6	0	8.69	30.2	0	10.69	37.1	0	9.69	33.6	0	7.56	26.2
11	2.5	12.75	45.5	0	10.81	37.6	0	8.69	30.2	0	10.69	37.1	0	9.69	33.6	0	7.56	26.2
14	3.5	12.75	45.9	0	10.81	37.6	0	8.69	30.2	3.0	10.69	38.3	2.0	9.69	34.3	0	7.56	26.2
16	4.0	12.75	46.2	0	10.75	37.3	0	8.56	29.7	3.0	10.69	38.3	2.0	9.69	34.3	0	7.56	26.2
18		12.19	44.1	0	10.75	37.3	0	8.56	29.7	3.0	10.69	38.3	2.0	9.69	34.3	0	7.56	26.2
32	5.0	11.69	42.7	0	10.44	36.3	0	8.50	29.5	7.0	10.19	38.1	4.0	9.50	34.3	0	7.50	26.0
38	7.0	11.69	43.7	1.0	10.44	36.7	1.0	8.50	29.8	7.5	10.19	38.3	4.0	9.50	34.3	0	7.50	26.0
41	8.0	11.69	44.1	1.0	10.44	36.7	1.0	8.50	29.8	8.0	10.19	38.5	4.5	9.37	34.0	0	7.50	26.0
46	8.5	11.44	43.4	2.0	10.[illegible]	36.6	1.5	8.50	29.9	12.0	9.94	39.2	6.0	9.31	34.4	0	7.50	26.0
48	9.5	11.44	43.9	2.0	10.31	36.6	1.5	8.44	29.7	12.0	9.94	39.2	6.0	9.31	34.4	0	7.44	25.8
52	10.0	11.31	43.7	2.0	10.19	36.4	1.5	8.44	29.7	12.0	9.94	39.2	6.0	9.31	34.4	0	7.44	25.8
55		11.31	43.7	2.0	10.19	36.4	1.5	8.44	29.7	12.5	9.94	39.4	6.5	9.31	34.6	0	7.44	25.8
59		11.19	43.2	2.0	10.19	36.4	1.5	8.44	29.7	14.0	9.94	40.1	8.0	9.19	34.7	0	7.44	25.8
66	11.5	11.06	43.4	3.0	10.06	35.9	2.0	8.44	29.9	15.5	9.81	40.2	8.0	9.13	34.5	1.5	7.37	25.9
73	13.5	10.88	43.7	3.0	10.06	35.9	2.5	8.31	29.6	17.0	9.69	40.5	9.5	9.06	34.8	1.5	7.37	25.9
80	14.5	10.81	43.9	4.0	9.94	35.9	3.0	8.31	29.7	17.0	9.69	40.5	9.5	9.06	34.8	1.5	7.25	25.9
94	16.0	10.81	44.7	5.0	9.75	35.6	3.0	8.13	29.1	20.0	9.38	40.7	11.0	8.63	33.6	2.0	7.19	25.5
102	16.5	10.44	43.4	5.0	9.75	35.6	3.0	8.13	29.1	20.0	9.38	40.7	11.0	8.56	33.4	2.5	7.13	25.4
108	17.5	10.25	43.1	5.5	9.19	33.7	3.0	7.94	28.4	20.5	9.38	41.0	11.0	8.50	33.1	2.5	7.13	25.4

TABLE II-17 (Continued)

Sample Code	F-20-0			F-30-0			F-60-0			M-20-0			M-30-0			M-60-0		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
115	17.5	10.25	43.1	5.5	9.19	33.7	3.5	7.94	28.5	21.0	9.31	40.9	11.0	8.44	32.9	2.5	7.06	25.1
122	17.5	10.06	42.3	6.0	9.06	33.4	3.5	7.87	28.3	22.5	9.25	41.3	11.0	8.44	32.9	2.5	7.06	25.1
129	19.0	9.94	42.6	7.0	9.06	33.8	3.5	7.87	28.3	23.5	9.25	41.9	11.0	8.44	32.9	2.5	7.06	25.1
136	20.0	9.94	43.1	7.0	9.06	33.8	4.0	7.87	28.4	23.5	9.25	41.9	11.5	8.38	32.9	2.5	7.06	25.1
144	22.0	9.69	43.1	7.0	8.94	33.4	4.0	7.81	28.2	23.5	9.13	41.4	11.5	8.31	32.6	2.5	7.06	25.1
152	23.0	9.56	43.1	7.5	8.87	33.3	4.0	7.75	28.0	23.5	9.13	41.4	11.5	8.31	32.6	2.5	7.06	25.1
159	25.0	9.56	44.2	7.5	8.87	33.3	4.0	7.75	28.0	23.5	9.13	41.4	11.5	8.19	32.1	2.5	7.00	24.9
166	25.5	9.56	44.5	7.5	8.81	33.0	4.0	7.75	28.0	23.5	9.13	41.4	13.0	8.13	32.4	2.5	7.00	24.9
173	26.5	9.50	46.1	8.0	8.81	33.2	5.0	7.63	27.9	24.5	8.56	39.4	13.5	7.88	31.6	3.0	6.88	24.6
180	28.5	9.50	46.1	8.5	8.75	33.2	6.0	7.56	27.9	25.5	8.56	39.8	14.5	7.75	31.5	3.5	6.75	24.2
187	29.0	9.50	46.5	9.0	8.69	33.2	6.0	7.56	27.9	26.5	8.44	39.9	16.5	7.56	31.4	4.0	6.69	24.2
194	34.0	9.50	49.9	9.5	8.56	32.8	6.0	7.56	27.9									

NOTES: (1) Sample Code: F-20-0,...refuse material size-paper content, percent-water saturation,percent.

(2) U: Percent subsidence

(3) W: Cell weight, lb

(4) γ: Cell unit weight, lb/cu ft

TABLE II-17 (Continued)

Sample Code	C-20-0			C-30-0			C-60-0			F-20-65			F-30-65			F-60-65		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
0	0	9.81	34.0	0	9.13	31.7	0	5.88	20.4	0	14.25	49.5	0	14.81	51.5	0	13.50	46.9
1	0	9.81	34.0	0	9.13	31.7	0	5.88	20.4	0	14.25	49.5	0	14.81	51.5	0	13.50	46.9
2	0	9.81	34.0	0	9.13	31.7	0	5.88	20.4	0	14.25	49.5	0	14.81	51.5	0	13.50	46.9
3	0	9.81	34.0	0	9.13	31.7	0	5.88	20.4	0	14.25	49.5	0	14.81	51.5	0	13.50	46.9
4	0	9.81	34.0	0	9.13	31.7	1.5	5.88	20.7	0	14.25	49.5	0	14.81	51.5	0	13.50	46.9
5	0	9.81	34.0	0	9.13	31.7	1.5	5.88	20.7	1.0	14.25	50.0	2.0	14.81	52.6	0	13.50	46.9
6	0	9.81	34.0	0	9.13	31.7	3.0	5.88	21.0	1.0	14.25	50.0	3.0	14.81	53.1	0	13.50	46.9
10	3.0	9.81	35.1	1.0	9.13	32.0	3.5	5.88	21.1	1.5	14.25	50.3	4.0	14.81	53.7	0	13.50	46.9
11	4.0	9.81	35.4	1.5	9.13	32.2	4.0	5.88	21.3	2.5	14.25	50.8	5.0	14.81	54.2	0	13.50	46.9
14	5.5	9.81	36.0	3.0	9.13	32.7	5.0	5.88	21.5	2.5	14.25	50.8		14.69	53.7	0	13.31	46.2
16	8.0	9.81	37.0	3.0	9.06	32.4	5.0	5.88	21.5	2.5	14.25	50.8		14.69	53.7	0	13.31	46.2
18	8.0	9.63	36.3	3.0	9.06	32.4	5.0	5.88	21.5	3.5	13.88	49.9	7.0	14.50	54.1	0	13.31	46.2
32	12.0	9.25	37.4	5.5	8.88	32.6	5.5	5.81	21.3	3.5	13.75	49.5	8.0	14.38	54.3	0	12.94	44.9
38	12.0	9.13	36.0	5.5	8.88	32.6	5.5	5.81	21.3	3.5	13.75	49.5	9.0	14.33	54.9	0	12.94	44.9
41	14.0	9.13	36.9	5.5	8.88	32.6	5.5	5.75	21.1	3.5	13.56	48.8	9.0	14.25	54.3	0	12.94	44.9
46	14.0	9.00	35.3	5.5	8.81	32.4	6.5	5.75	21.3	3.5	13.50	48.6	9.0	14.13	53.9	0	12.88	44.7
48	17.0	9.00	37.7	7.5	8.69	32.6	7.0	5.69	21.3	4.0	13.50	48.8	9.0	14.13	53.9	0	12.88	44.7
51	17.5	8.94	37.6	7.5	8.69	32.6	7.0	5.69	21.3	4.0	13.50	48.8	9.5	14.13	54.2	0	12.88	44.7
55	17.5	8.94	37.6	7.5	8.69	32.6	7.0	5.69	21.3	4.0	13.50	48.8	10.0	14.13	54.5	0	12.88	44.7
59	19.0	8.81	36.8	8.5	8.69	33.0	7.0	5.69	21.3	7.5	13.44	50.5	13.0	14.06	56.0	1.0	12.81	44.8
66	21.0	8.75	38.4	10.5	8.63	33.5	8.0	5.69	21.5	8.0	13.25	50.0	14.5	13.88	56.3	1.0	12.75	44.7
73	23.0	8.63	38.9	12.0	8.50	33.5	8.0	5.56	21.0	8.5	13.13	49.8	16.0	13.75	56.9	1.5	12.63	44.5
80	23.0	8.56	38.6	12.5	8.44	33.5	8.5	5.56	21.1	10.0	12.88	49.7	17.5	13.44	56.5	1.5	12.50	44.0
92	27.0	8.56	40.7	15.0	8.19	33.5	10.0	5.19	20.0	11.5	12.50	49.0	19.0	13.19	55.5	1.5	12.31	43.3
102	29.0	8.13	39.7	15.0	8.19	33.5	11.0	5.06	19.7	12.5	12.44	49.5	20.0	13.06	56.6	2.0	12.31	43.6
108	30.0	8.00	39.7	16.0	8.19	33.9	11.0	4.94	19.3	12.5	12.31	48.8	20.5	13.00	56.8	2.0	12.25	43.4

TABLE II-17 (Continued)

Sample Code	C-20-0			C-30-0			C-60-0			F-20-65			F-30-65			F-60-65		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
115	30.5	8.00	40.0	16.0	8.06	33.3	11.5	4.94	19.4	14.5	11.94	48.5	22.5	12.50	56.0	2.0	12.19	43.1
122	31.0	7.94	39.9	16.0	8.00	33.1	11.5	4.94	19.4	16.0	11.88	49.2	24.5	12.44	57.2			
129	32.5	7.94	40.8	16.0	8.00	33.1	12.0	4.94	19.5	18.0	11.88	50.3	25.0	12.38	57.3			
136	34.5	7.94	42.0	16.0	8.00	33.1	12.0	4.94	19.5	19.5	11.50	49.7	27.5	12.25	58.7			
144	35.0	7.88	42.1	16.0	8.00	33.1	12.0	4.94	19.5	21.0	11.25	49.5	28.5	12.06	53.6			
149	36.0	7.63	41.4	16.0	7.94	32.8	12.5	4.81	19.1	22.5	11.00	49.3	30.0	11.94	59.2			
156	37.5	7.50	41.6	16.0	7.94	32.8	12.5	4.81	19.1	24.0	10.88	49.7	31.0	11.75	59.2			
163	39.5	7.36	42.2	16.0	7.94	32.8	13.0	4.75	18.9	25.0	10.75	49.8	32.5	11.63	59.8			
170	40.0	7.31	42.3	16.0	7.75	32.2	13.0	4.75	18.9	26.5	10.69	50.5	35.0	11.25	60.1			
177	41.0	7.06	41.5	16.0	7.69	31.8	13.5	4.69	18.8	30.0	10.19	50.6	38.5	10.94	61.7			
184	43.5	6.94	42.6	16.0	7.50	31.0	13.5	4.69	18.8	34.0	9.88	52.0	38.5	10.94	61.7			
191	45.5	6.56	41.8	16.0	7.50	31.0	14.0	4.69	18.9	34.0	9.69	51.0	42.0	10.63	63.6			

NOTES: (1) Sample Code: F-20-0, ... refuse material size-paper content, percent,-water saturation, percent.

(2) U: Percent subsidence.

(3) W: Cell weight, lb.

(4) γ. Cell unit weight, lb/cu ft.

TABLE II-17 (Continued)

Sample Code	M-20-65			M-30-65			M-60-65			C-20-65			C-30-65			C-60-65		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
0	0	16.06	55.7	0	16.63	57.7	0	13.81	48.0	0	15.88	55.1	0	16.00	55.5	0	15.25	53.0
13	3.5	15.56	56.0	2.0	16.31	57.7	0	13.75	47.7	3.5	15.56	56.0	0	14.88	51.6	0	15.06	52.2
19	3.5	15.31	55.0	2.5	16.13	57.5	0	13.44	46.7	3.5	14.00	50.5	2.5		53.0	0	15.06	52.2
22	3.5	15.31	55.0	2.5	16.13	57.5	0	13.44	46.7	3.5			2.5		53.0	0		52.2
27	3.5	15.25	55.0	2.5	16.00	57.0	0	13.44	46.7	6.0	13.75	49.7	4.0	14.63	53.0	0	14.81	51.4
29	4.0	15.25	55.3	2.5	16.00	57.0	0	13.31	46.2	6.0	13.75	49.7	4.0	14.63	53.0	0		51.4
32	4.0	14.75	53.3	2.5	15.88	56.6	0	13.31	46.2	6.0	13.69	50.5	4.0	14.50	52.4	0	14.56	50.5
36	4.0	14.75	53.3	2.5	15.88	56.6	0	13.25	46.0	6.0	13.69	50.5	4.0		52.4	0		50.5
40	4.0	14.56	52.7	2.5	15.81	56.3	0	13.25	46.0	6.0	13.50	50.1	4.0	14.31	51.7	0	14.50	50.3
47	7.5	14.44	54.2	6.0	15.75	58.2	2.0	13.19	46.7	6.5	13.31	49.4	4.0	14.25	51.5	0	14.38	49.8
54	9.5	14.25	54.7	6.5	15.69	58.2	3.0	13.13	47.0	7.0	13.31	49.7	4.5	14.25	51.7	0	14.25	49.4
61	11.5	14.13	55.4	8.0	15.50	58.5	3.0	13.00	46.5	11.0	13.00	50.7	8.5	14.13	53.6	2.0	14.25	50.5
75	12.0	13.88	54.8	9.5	15.31	58.8	3.5	12.81	46.0	16.0	12.69	52.4	12.0	13.81	54.5	3.5	14.19	51.0
84	13.0	13.44	53.6	10.0	15.31	59.1	3.5	12.75	45.9	18.0	12.69	53.7	14.0	13.75	55.5	5.0	14.06	51.4
89	13.5	13.44	54.0	10.5	15.06	58.4	3.5	12.75	45.9	18.0	12.44	52.7				5.0	14.05	51.4
96	13.5	13.38	53.7	10.5	15.06	58.4	3.5	12.75	45.9	19.0	11.63	49.8				5.0	14.06	51.4
103	14.0	13.25	53.5	11.0	14.81	57.7	3.5	12.75	45.9	20.5	10.88	47.5				5.0	13.81	50.5
110	15.0	12.88	52.6	12.0	14.63	57.8				20.5	10.88	47.5				5.0	13.81	50.5
117	15.5	12.75	52.3	13.0	14.19	56.7				21.5	10.38	45.9				5.0	13.56	49.6
125	16.5	12.50	52.0	14.0	13.88	56.0				22.5	10.38	46.4				5.5	13.50	49.5
131	16.5	12,25	51.0	15.0	13.56	55.4				24.0	10.13	46.3				5.5	13.44	49.4
138	17.5	12.00	50.5	16.5	13.50	56.1				25.0	9.88	45.7				5.5	13.38	49.1
145	20.0	11.56	50.2	18.0	13.13	55.6				26.0	9.69	45.4				5.5	13.31	48.9
152	21.5	11.25	49.8	20.0	12.88	55.9				28.0	9.56	46.0				6.0	13.31	49.1
159	23.5	10.81	49.1	22.0	12.31	54.7				30.0	9.38	46.5				6.5	13.19	49.0
166	26.0	10.13	47.6	24.5	11.69	53.8				32.0	9.13	46.6				6.5	13.13	48.8
173	29.0	9.50	46.4	27.0	11.06	52.6				35.5	8.63	45.3				6.5	12.94	48.0

TABLE II-17 (Continued)

Sample Code	M-20-65			M-30-65			M-60-65			C-20-65			C-30-65			C-60-65		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
179										39.0	8.38	47.6						
186										40.5	7.94	46.3						

NOTES:

(1) Sample Code: F-20-0...refuse material size-paper content, percent-water saturation, percent

(2) U: Percent subsidence

(3) W: Cell weight, lb

(4) γ: Cell unit weight, lb/cu ft

TABLE II-18

SUBSIDENCE DURING ANAEROBIC DECOMPOSITION

Sample Code	F-20-0			F-30-0			F-60-0			M-20-0			M-30-0			M-60-0		
Time, Days	U	W	Y	U	W	Y	U	W	Y	U	W	Y	U	W	Y	U	W	Y
0	0	12.28	42.7	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
1	0	12.28	42.7	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
2	0.	12.28	42.7	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
3	0	12.28	42.7	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
4	0	12.28	42.7	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
5	0	12.28	42.7	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
6	1.0	12.28	43.1	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
7		12.28	43.1	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
8		12.28	43.1	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
9		12.28	43.1	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
10	3.0	12.28	44.0	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	0	6.38	22.2
11		12.28	44.0	0	10.94	38.0	0	8.75	30.4	0	10.69	37.1	0	9.00	31.3	1.0	6.38	22.4
14	3.5	12.28	44.3	0	10.94	38.0	0	8.75	30.4	2.0	10.69	37.9	0	9.00	31.3	1.0	6.38	22.4
16	4.5	12.28	44.7	0	10.81	37.6	0	8.75	30.4	2.0	10.69	37.9	0	9.00	31.3	1.0	6.38	22.4
18		12.28	44.7	0	10.81	37.6	0	8.75	30.4	2.0	10.69	37.9	0	9.00	31.3	1.0	6.38	22.4
32	5.5	12.28	44.7	0	10.81	37.6	0	8.75	30.4	3.0	10.50	37.6	2.0	8.81	31.2	2.0	6.38	22.7
38	6.0	12.16	44.8	0	10.81	37.6	0	8.75	30.4	3.5	10.50	37.8	2.0	8.69	30.8	2.0	6.38	22.7
41	6.0	12.16	44.8	0	10.81	37.6	0	8.75	30.4	3.5	10.50	37.8	2.5	8.69	30.9	2.0	6.38	22.7
46	6.0	12.16	44.8	0	10.81	37.6	0	8.75	30.4	4.0	10.50	38.0	2.5	8.69	30.9	2.0	6.38	22.7
48	6.5	12.16	44.8	0	10.81	37.6	0	8.75	30.4	4.5	10.44	38.0	2.5	8.69	30.9	2.0	6.38	22.7
51	6.5	12.09	44.9	0	10.81	37.6	0	8.75	30.4	4.5	10.44	38.0	3.0	8.69	31.1	2.0	6.38	22.7
55	7.0	12.09	45.1	0	10.81	37.6	0	8.75	30.4	5.5	10.44	38.4	3.0	8.69	31.1	2.0	6.38	22.7
59	7.0	12.09	45.1	0	10.75	37.4	0	8.75	30.4	9.5	10.44	40.1	3.0	8.62	30.8	2.0	6.38	22.7
66	10.0	12.03	46.5	1.5	10.50	37.0	0	8.75	30.4	9.5	10.44	40.1	6.0	8.62	31.8	3.0	6.38	22.9
73	10.5	12.03	46.7	2.0	10.50	37.2	0	8.75	30.4	10.0	10.38	40.1	6.0	8.56	31.6	3.0	6.25	22.4
80	11.0	11.97	46.8	2.0	10.44	37.0	0	8.75	30.4	11.0	10.31	40.3	6.5	8.56	31.8	3.0	6.19	22.1
92	13.0	11.97	47.7	4.0	10.38	37.5	1.5	8.69	30.7	17.0	10.25	42.9	10.0	8.44	32.5	5.0	6.06	22.1

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TABLE II-18 (Continued)

Sample Code	F-20-0			F-30-0			F-60-0			M-20-0			M-30-0			M-60-0		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
103	14.0	11.84	47.9	5.0	10.13	37.0	2.0	8.63	30.6	17.0	9.94	41.5	11.0	8.19	31.9	5.5	6.06	22.3
108	14.0	11.84	47.9	5.0	10.13	37.0	2.0	8.63	30.6	18.5	9.75	41.5	11.5	7.94	31.2	5.5	5.94	21.8
115	14.0	11.84	47.9	5.5	10.13	37.3	2.0	8.63	30.6	22.0	9.75	43.3	11.5	7.87	30.8	5.5	5.94	21.8
122	15.0	11.66	47.6	5.5	10.13	37.3	2.5	8.63	30.75	24.0	9.56	43.6	11.5	7.56	29.6	5.5	5.81	21.3
129	17.0	11.59	48.5	6.0	10.00	36.9	2.5	8.50	30.3	27.5	9.25	41.4	12.0	7.45	29.4			
136	18.0	11.53	48.8	6.5	9.88	36.7	2.5	8.44	30.1	29.5	9.19	45.2	12.5	7.45	29.5			
144	19.5	11.41	49.2	7.5	9.75	36.6	2.5	8.44	30.1	32.5	9.13	46.9	12.5	7.45	29.5			
151	20.5	11.41	49.9	7.5	9.75	36.6	2.5	8.31	29.6	35.0	8.94	47.7	12.5	7.31	29.0			
157	22.0	11.22	50.0	8.5	9.63	36.6	2.5	8.31	29.6	37.0	8.94	49.2	17.0	7.06	29.5			
165	22.5	11.09	49.7	8.5	9.56	36.3	2.5	8.25	29.4	38.5	8.88	50.1	22.5	6.94	27.5			
172	23.5	11.09	50.3	9.0	9.56	36.5	2.5	8.25	29.4	40.0	8.69	50.3	32.0	6.94	35.4			
179	25.0	10.91	50.6	9.0	9.56	36.5	2.5	8.25	29.4	41.5	8.50	50.4	36.5	6.81	37.9			
186	25.5	10.91	50.9	9.5	9.44	36.2	3.0	8.13	29.1	43.5	8.38	51.5	39.5	6,69	38.3			
193	27.0	10.78	51.4	10.0	9.38	36.2	3.0	8.13	29.1	45.0	8.19	51.7	41.5	6.69	39.7			

NOTES: (1) Sample Code: F-20-0, ... refuse material size-paper content, percent,-water saturation, percent.

(2) U: Percent subsidence.

(3) W: Cell weight, lb.

(4) γ: Cell unit weight, lb/cu ft.

TABLE II-18 (Continued)

Sample Code	C-20-0			C-30-0			C-60-0			F-20-65			F-30-65			F-60-65		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
0	0	10.19	35.4	0	9.62	33.4	0	6.13	21.5	0	13.81	48.0	0	14.31	49.7	0	14.13	49.0
1	0	10.19	35.4	0	9.62	33.4	0	6.13	21.5	0	13.81	48.0	0	14.31	49.7	0	14.13	49.0
5	0	10.19	35.4	0	9.62	33.4	0	6.13	21.5	3.5	13.81	49.7	3.0	14.31	51.2	0	14.13	49.0
6	0	10.19	35.4	0	9.62	33.4	0	6.13	21.5	4.5	13.81	50.3	4.0	14.31	51.8	0	14.13	49.0
8	0	10.19	35.4	0	9.62	33.4	1.0	6.13	21.7	4.5	13.81	50.3	4.0	14.31	51.8	0	14.13	49.0
9	0	10.19	35.4	1.0	9.62	33.8	1.0	6.13	21.7	5.5	13.81	50.8	4.5	14.31	52.0	0	14.13	49.0
10	2.0	10.19	36.1	1.0	9.62	33.8	1.0	6.13	21.7	5.5	13.81	50.8	4.5	14.31	52.0	0	14.13	49.0
11	2.0	10.19	36.1	1.0	9.62	33.8	1.5	6.13	21.8	6.5	13.81	51.4	5.0	14.31	52.3	0	14.13	49.0
14	4.0	10.19	36.9	1.0	9.62	33.8	2.0	6.13	21.9	6.5	13.81	51.4	5.0	14.31	52.3	0	14.06	48.8
16	6.5	10.19	37.9	1.0	9.62	33.8	2.0	6.13	21.9	6.5	13.81	51.4	5.0	14.31	52.3	0	14.06	48.8
18	6.5	10.19	37.9	2.0	9.62	34.1	2.0	6.13	21.9	6.5	13.75	51.0	5.0	13.94	50.9	0	14.06	48.3
32	7.5	10.19	38.3	3.5	9.56	34.4	2.0	6.13	21.9	7.5	13.69	51.7	6.0	13.94	51.5	0	13.88	48.2
38	8.0	10.19	38.5	3.5	9.56	34.4	2.0	6.13	21.9	8.0	13.69	52.0	6.0	13.94	51.5	0	13.88	48.2
41	8.0	10.19	38.5	4.0	9.56	34.6	2.0	6.13	21.9	8.0	13.63	51.5	6.5	13.88	51.5	0	13.81	48.0
46	8.0	10.06	38.0	4.0	9.56	34.6	2.0	6.13	21.9	8.0	13.44	50.7	7.5	13.63	51.1	0	13.81	48.0
48	8.0	10.06	38.0	4.0	9.50	34.3	2.0	6.13	21.9	8.5	13.44	51.0	7.5	13.63	51.1	0	13.81	48.0
51	8.5	10.06	38.2	4.0	9.50	34.3	2.0	6.13	21.9	9.0	13.44	51.3	7.5	13.63	51.1	0	13.81	48.0
55	9.0	10.06	38.4	4.0	9.50	34.3	2.0	6.13	21.9	10.0	13.25	51.1	8.0	13.63	51.4	0	13.81	48.0
59	9.0	10.06	38.4	4.0	9.50	34.3	2.5	6.13	22.1	12.0	12.94	51.1	10.5	13.50	52.3	1.0	13.75	48.2
66	11.0	10.06	39.3	5.5	9.50	34.9	3.0	6.13	22.2	13.0	12.88	51.3	11.0	13.44	52.4	1.0	13.75	48.2
73	11.5	10.06	39.5	6.0	9.44	34.9	3.0	5.94	21.3	13.0	12.75	50.7	11.5	13.31	52.2	1.0	13.75	48.2
80	12.0	10.00	39.5	6.0	9.44	34.9	3.5	5.94	21.4	18.0	12.75	54.0	11.5	13.31	52.2	1.0	13.63	47.7
92	14.0	9.88	39.9	9.0	9.44	36.0	5.0	5.88	21.5	20.0	12.56	54.5	13.5	13.13	52.7	1.5	13.50	47.6
103	16.0	9.88	40.8	10.0	9.19	35.4	5.3	5.81	21.3	20.0	12.44	54.0	16.0	12.31	50.8	2.0	13.50	47.8
108	17.0	9.69	40.5	10.0	9.13	35.2	5.5	5.81	21.4	20.5	12.31	53.8	16.5	11.94	49.7	2.0	13.44	47.6
115	17.5	9.56	40.2	10.0	9.13	35.2	5.5	5.81	21.4	22.0	12.31	54.9	19.0	11.81	50.6	2.0	12.94	45.8
122	19.5	9.44	40.7	10.5	9.06	35.1	5.5	5.81	21.4	23.0	11.81	53.3	21.5	11.31	50.0			

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TABLE II-18 (Continued)

Sample Code	C-20-0			C-30-0			C-60-0			F-20-65			F-30-65			F-60-65		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W		U	W	γ
129	20.5	9.44	41.2	12.0	9.06	35.7	5.5	5.75	21.2	23.5	11.69	53.0	22.5	11.31	50.7			
136	22.0	9.19	40.8	12.5	9.00	35.6	6.0	5.75	21.2	25.0	11.63	53.9	23.0	11.31	51.0			
144	24.0	9.06	41.3	13.0	8.94	35.6	6.0	5.69	21.0	26.5	11.50	54.3	24.5	11.19	51.4			
151	25.5	9.00	41.9	14.0	8.81	35.5	6.0	5.69	21.0	27.5	11.44	54.8	25.5	11.19	52.1			
158	27.0	9.00	42.8	14.5	8.81	35.8	6.5	5.69	21.1	28.5	11.31	54.9	26.5	11.06	52.0			
165	28.0	8.94	43.0	15.0	8.81	36.0	6.5	5.63	20.9	29.5	11.25	55.4	27.0	10.94	52.1			
172	30.0	8.88	44.0	16.0	8.81	36.4	6.5	5.63	20.9	31.0	10.94	55.0	28.5	10.81	52.5			
179	32.0	8.69	44.3	16.5	8.63	35.9	6.5	5.56	20.6	31.0	10.81	54.4	29.5	10.81	53.2			
186	35.0	8.56	45.7	16.5	8.56	35.5	6.5	5.56	20.6	33.0	10.81	56.0	31.0	10.69	53.8			
193	36.5	8.56	46.8	17.5	8.56	36.0	6.5	5.56	20.6	33.5	10.75	56.2						

NOTES: (1) Sample Code: F-20-0, ...refuse material size-paper content, percent,-water saturation, percent.

(2) U: Percent subsidence.

(3) W: Cell weight, lb.

(4) γ: Cell unit weight, lb/cu ft.

TABLE II-18 (Continued)

Sample Code	M-20-65			M-30-65			M-60-65			C-20-65			C-30-65			C-60-65		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
0	0	15.19	52.7	0	15.63	54.3	0	14.0	48.6	0	16.0	55.5	0	16.31	56.7	0	15.38	53.4
8	0	15.19	52.7	0	15.63	54.3	0	14.0	48.6	0	14.69	51.0	2.0	16.13	57.1	0	15.38	53.4
13	1.5	15.00	53.2	0	15.06	52.3	0	14.0	48.6	1.5	13.94	49.2	3.0	16.00	57.3	0	15.13	52.6
19	2.0	14.50	51.3	0	14.38	49.8	0	13.88	48.2	3.5		50.1		16.00	57.3	0	15.13	52.6
22	2.5	14.50	51.7	0	14.38	49.8	0	13.88	48.2	3.5	13.88	49.9		15.94	57.0	0	15.13	52.6
27	2.5	14.50	51.7	0	14.38	49.8	0	13.81	48.0	3.5	13.88	49.9	5.0	15.94	58.3	0	15.06	52.3
29	2.5	14.50	51.7	0	14.38	49.8	0	13.81	48.0	3.5	13.88	49.9	5.0	15.94	58.3	0	15.06	52.3
32	2.5	14.50	51.7	0	14.38	49.8	0	13.81	48.0	4.0	13.88	50.2	5.0	15.50	56.6	0	14.75	51.2
36	2.5	14.50	51.7	0	14.38	49.8	0	13.81	48.0	4.0	13.88	50.2	5.5	15.50	56.9	0	14.75	51.2
40	4.0	14.13	51.1	0	14.19	49.2	0	13.81	48.0	4.5	13.88	50.5	6.0	15.50	57.3	0	14.75	51.2
47	6.5	13.94	51.7	4.0	14.19	51.2	0	13.81	48.0	5.0	13.81	50.5	6.0	15.50	57.3	0	14.69	51.0
54	7.0	13.88	51.8	4.0	14.00	50.7	0	13.75	47.7	5.0	13.56	49.5	7.0	15.25	57.0	0	14.69	51.0
61	7.5	13.75	51.7	4.0	13.88	50.2	0	13.75	47.7	9.0	13.44	51.3	11.5	15.06	59.1	1.0	14.69	51.5
75	11.0	13.31	51.9	6.0	13.88	51.2	0	13.75	47.7	9.5	13.00	49.9	12.0	14.88	58.7	1.0	14.69	51.5
84	12.5	12.56	49.9	6.0	13.38	49.4	1.0	13.69	48.0	9.5		49.9		14.88	58.7	1.0	14.69	51.5
89	13.0	12.38	49.4	6.5	13.31	49.3	1.0	13.63	47.8	12.0	12.75	50.3	15.0	14.60	59.2	3.0	14.56	52.0
96	14.0	11.94	48.2	6.5	13.31	49.3	1.0	13.50	47.3	13.0	12.31	49.2	15.0	14.19	57.9	3.5	14.31	51.4
103	15.0	11.81	48.3	6.5	13.19	49.0	1.0	13.44	47.1	13.5	12.25	49.2	15.5	14.19	58.3	3.5	14.19	50.9
110	16.0	11.75	48.6	7.5	13.13	49.3				14.0	12.00	48.5	16.0	13.69	56.6	3.5	14.00	50.3
117	17.5	11.75	49.5	8.0	13.06	49.3				15.0	11.75	48.0	16.0	13.69	56.6	3.5	13.88	49.8
125	19.0	11.63	49.9	9.0	12.69	48.4				15.5	11.56	47.5	16.0	13.69	56.6	4.0	13.88	50.1
131	20.0	11.50	49.9	9.5	12.56	48.0				16.0	11.25	46.5	16.0	13.56	56.0	4.0	13.75	49.7
138	21.0	11.38	50.0	10.0	12.44	48.0				17.0	11.19	46.8	16.0	13.38	55.2	4.5	13.75	50.0
145	21.5	11.25	49.8	10.5	12.31	47.8				18.5	10.88	46.3	16.5	13.19	54.8	4.5	13.56	49.2
152	22.5	11.00	49.2	11.0	12.06	47.0				20.0	10.69	46.3	17.0	13.06	54.6	5.0	13.56	49.5
159	24.0	10.69	48.9	12.0	11.88	46.8				20.5	10.50	45.8	17.5	13.00	54.7	5.5	13.44	49.3
166	25.0	10.50	48.7	13.0	11.63	46.4				21.5	10.25	45.4	18.0	12.94	54.7	6.0	13.38	49.4

TABLE II-18 (Continued)

Sample Code	M-20-65			M-30-65			M-60-65			C-20-65			C-30-65			C-60-65		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
173	25.5	10.38	48.5	13.5	11.5	46.2				23.5	10.00	45.3	19.5	12.63	54.6	6.5	13.38	49.7
180										25.0	9.75	45.1	20.5	12.56	54.8	6.5	13.31	49.4
186										26.0	9.56	44.8	22.0	12.44	55.4	6.5	13.19	48.9

NOTES: (1) Sample Code: F-20-0, ... refuse material size-paper content, percent,-water saturation, percent.

(2) U: Percent subsidence.

(3) W: Cell weight, lb.

(4) γ: Cell unit weight, lb/cu ft.

TABLE II-18 (Continued)

Sample Code	F-20-100			F-30-100			F-60-100			M-20-100			M-30-100			M-60-100		
Time, Days	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ	U	W	γ
0	0	15.88	55.1	0	16.94	63.5	0	18.31	63.6	0	19.13	66.4	0	21.06	73.1	0	16.88	58.7
11	16.0	13.14	54.3	4.0	15.63	56.5	0	16.88	58.5	6.0	14.88	55.0	2.0	16.25	57.6	0	15.75	54.7
17	17.0	12.26	51.3	5.0	15.32	56.0	0	16.25	56.4	6.5	14.88	55.2	2.0	16.25	57.6	0	15.75	54.7
20	18.0	12.26	51.9	5.0	15.32	56.0	0	16.13	56.0	7.0	14.88	55.5	2.0	16.25	57.6	0	15.75	54.7
25	19.0	12.26	52.5	5.0	15.32	56.0	0	16.13	56.0	7.0	14.88	55.5	2.0	16.25	57.6	0	15.75	54.7
27	19.0	12.26	52.5	5.0	15.32	56.0	0	16.13	56.0	7.0	14.88	55.5	2.0	16.25	57.6	0	15.75	54.7
30	19.0	12.26	52.5	5.0	15.32	56.0	0	16.13	56.0	7.0	14.81	55.3	2.0	16.25	57.6	0	15.75	54.7
34	19.0	12.26	52.5	5.0	15.32	56.0	0	16.13	56.0	7.5	14.81	55.6	2.0	16.25	57.6	0	15.75	54.7
38	19.5	12.26	52.8	5.0	15.32	56.0	1.0	16.13	56.5	7.5	14.75	55.3	2.0	16.06	56.9	0	15.75	54.7
45	21.5	12.08	53.4	7.5	15.25	57.3	1.5	16.13	56.9	10.0	14.56	56.2	3.5	16.06	57.8	1.5	15.75	55.5
52	22.0	12.01	53.3	8.0	15.25	57.6	1.5	16.06	56.6	10.5	14.44	56.1	3.5	16.00	57.6	1.5	15.75	55.5
59	22.0	12.01	53.3	8.0	15.25	57.6	1.5	16.06	56.6	11.0	14.38	56.1	3.5	16.00	57.6	2.0	15.75	55.8
73	25.0	11.76	54.4	9.5	15.07	57.7	1.5	15.88	56.0	13.0	13.06	52.1	5.0	15.75	57.6	2.0	15.75	55.8
82	25.0	11.70	54.2	10.0	14.69	56.6	2.0	15.81	56.0	14.5	12.63	51.3	5.0	15.25	55.7	2.5	15.75	56.1
87	26.5	11.51	54.4	10.5	14.69	57.0	2.0	15.63	55.3	15.5	12.19	50.0	6.0	15.06	55.7	3.0	15.56	55.7
94	26.5	11.51	54.4	11.0	14.69	57.2	2.0	15.63	55.3	16.5	11.81	49.1	6.0	14.63	51.0	3.0	15.56	55.7
101	27.5	11.80	56.4	11.5	14.57	57.2	2.0	15.63	55.3	18.5	11.69	49.8	6.0	14.50	50.4	3.0	15.38	55.0
108	28.5	11.08	53.8	12.0	14.50	57.2				20.5	11.50	50.2	6.0	14.44	50.2			
115	29.5	10.89	53.6	12.5	14.44	57.3				21.0	11.31	49.7	7.0	14.13	52.7			
123	30.5	10.64	53.2	13.0	14.32	57.2				23.0	11.00	49.6	8.0	13.75	51.9			
129	32.5	10.45	53.7	14.0	14.19	57.2				24.0	10.88	49.7	8.5	13.75	52.2			
136	32.5	10.45	53.7	15.0	14.00	57.1				25.0	10.75	49.8	9.5	13.44	51.6			
143	33.5	10.26	53.6	16.0	14.00	56.5				26.5	10.56	49.8	10.5	13.25	51.4			
150	34.0	10.01	57.6	17.0	13.94	58.3				27.5	10.38	49.7	11.0	13.13	51.3			
157	35.0	9.76	52.1	18.0	13.74	58.1				30.0	10.06	49.5	12.0	12.88	50.8			
164	36.0	9.58	52.0	18.5	13.69	58.3				31.5	9.81	49.6	13.5	12.69	50.8			

TABLE II-18 (Continued)

Sample Code	C-20-100			C-30-100			C-60-100			Sample Code	C-20-(30)			C-30-(30)			C-60-(30)		
Time, Days	U	W	γ	U	W	γ	U	W	γ	Time, Days	U	W	γ	U	W	γ	U	W	γ
0	0	23.63	82.0	0	21.13	73.3	0	20.81	72.3	0	0	12.19	42.3	0	10.25	35.6	0	7.75	26.9
13	8.0	-	-	3.0	-	-	1.0	-	-	7	0	12.19	42.3	0	10.25		0	7.75	26.9
19	8.5	16.94	64.3	3.5	15.00	54.0	1.0	15.81	55.4	15	0	12.19	42.3	0	10.25		5.0	7.69	
22	9.0	16.94	64.5	3.5	15.00	54.0	1.5	15.81	55.7	21	0	12.13		0	10.19		5.0	7.69	
27	9.0	16.81	64.2	4.0	14.94	53.8	1.5	15.81	55.7	28	0.5	12.06		0	10.06		5.5	7.63	
29	9.5	16.81	64.5	4.0	14.94	53.8	1.5	15.81	55.7	35	0.5	11.94		0	10.06		5.5	7.63	
32	9.5	16.81	64.5	4.0	14.75	53.3	1.5	15.81	55.7	42	1.5	11.88		1.0	10.06		6.0	7.63	
36	10.0	16.81	64.9	4.0	14.75	53.3	1.5	15.81	55.7	49	2.5	11.75		2.0	10.00		6.0	7.50	
40	10.0	16.56	63.8	4.5	14.63	53.2	2.0	15.81	56.0	56	3.5	11.56		2.0	10.00		6.0	7.50	
47	15.0	16.19	66.1	8.0	14.44	54.5	2.5	15.81	56.2	63	5.0	11.38		2.0	10.00		6.0	7.38	
54	15.0	16.00	65.4	8.0	14.31	54.0	2.5	15.81	56.2										
61	15.0	15.88	64.8	8.5	14.25	54.1	2.5	15.81	56.2										
75	18.0	15.38	65.0	11.0	14.06	54.8	2.5	15.81	56.2										
84	20.0	15.19	65.9	12.0	13.63	53.7	3.0	15.69	56.2										
89	20.5	15.13	66.0	12.5	13.56	53.8	3.0	15.63	55.8										
96	20.5	14.75	64.5	12.5	13.56	53.8	3.0	15.13	54.1										
103	22.0	14.63	65.0	12.5	13.56	53.8	3.0	15.06	53.8										
110	23.0	14.25	64.3	12.5	13.56	53.8	3.0	15.06	53.8										
117	23.5	14.00	63.6	12.5	13.44	53.3	3.0	14.94	53.3										
125	25.0	13.88	64.2	12.5	13.06	51.8	3.0	14.88	53.1										
131	26.5	13.63	64.3	13.0	13.06	52.1	3.5	14.88	53.5										
138	27.5	13.38	64.0	13.5	12.94	52.0	3.5	14.81	53.1										
145	29.0	13.31	65.1	14.0	12.94	52.1	3.5	14.81	53.1										

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TABLE II-18 (Continued)

Sample Code	C-20-100			C-30-100			C-60-100		
Time, Days	U	W	γ	U	W	γ	U	W	γ
152	29.5	13.13	64.7	14.0	12.94	52.1	3.5	14.81	53.1
159	30.0	12.88	63.9	15.0	12.69	52.1	3.5	14.75	52.8
166	31.5	12.81	65.0	16.0	12.69	52.4	4.0	14.63	52.8
173	34.5	12.69	67.2	17.5	12.50	49.5	4.0	14.63	52.8

NOTES: (1) Sample Code: F-20-0, ...refuse material size-paper content, percent,-water saturation, percent.

(2) U: Percent subsidence

(3) W: Cell weight, lb

(4) γ: Cell unit weight, lb/cu ft

TABLE II-19

CONSOLIDATION TEST DATA*
AEROBIC REFUSE - DRY

Refuse Size	Paper Content - Percent								
	20 Percent			30 Percent			60 Percent		
	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain %
Fine	1,257	1.00	25.0	1,257	1.00	25.0	1,257	0.80	20.0
	2,212	1.15	28.7	1,902	1.05	26.2	1,902	1.05	26.2
	3,130	1.30	32.5	3,115	1.30	32.5	2,509	1.10	27.5
	4,047	1.40	35.0	4,047	1.43	35.8	3,426	1.25	31.2
							4,047	1.35	33.7
Mixed	1,257	0.65	19.7	1,257	0.55	13.8	1,257	0.80	20.0
	1,902	0.75	22.7	1,902	1.20	30.0	2,205	1.10	27.5
	2,819	0.90	27.2	2,819	1.45	36.2	2,812	1.25	31.2
	4,047	1.05	31.8	3,426	1.48	37.0	3,426	1.40	35.0
				4,047	1.55	39.0	4,047	1.45	36.2
Coarse	1,257	1.30	36.0(a)	1,257	1.25	30.0(b)	1,257	0.55	13.8
	1,902	1.40	39.0	1,902	1.55	37.3			
	2,509	1.50	42.0	2,509	1.55	37.3	1,864	0.65	16.2
	3,426	1.60	44.0	3,426	1.65	39.7	2,175	0.70	17.5
							2,478	0.85	21.2
	4,046	1.70	47.0	4,047	1.75	42.1	3,092	0.90	22.3
							3,403	0.95	23.7

NOTES: (a) Sample height 3.6 inches.

(b) Sample height 4.15 inches.

* Unwetted, see Table II-12.

TABLE II-20

CONSOLIDATION TEST DATA
AEROBIC REFUSE - 65 PERCENT SATURATED

Refuse Size	Paper Content - Percent								
	20 Percent			30 Percent			60 Percent		
	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain %
Fine	1,257	1.15	28.7	1,257	0.85	22.4(a)			
	1,902	1.30	32.5	1,902	1.00	26.3			
	2,509	1.40	35.0	2,509	1.10	29.0			
	3,115	1.50	37.5	3,123	1.20	31.6			
	4,047	1.65	41.2	4,047	1.25	33.0			
Mixed	1,257	1.20	30.0	1,257	1.40	35.0			
	1,879	1.30	32.5	1,902	1.50	37.5			
	2,507	1.40	35.0	2,509	1.65	41.2			
	3,121	1,40	35.0	3,115	1.75	43.7			
	3,721	1.55	38.7	4,047	1.80	45.0			
Coarse	1,257	1.20	33.7(b)	1,257	1.25	31.2	1,257	1.25	31.2
	1,902	1.35	38.4	1,902	1.40	35.0	2,212	1.40	35.0
	2,509	1.40	39.4	2,509	1.60	40.0	3,130	1.50	37.5
	3,115	1.45	40.8	3,115	1.65	41.2	4,047	1.65	41.2
	4,047	1.55	43.6	4,047	1.75	43.7			

NOTES: (a) Sample height, 3.8 inches.
(b) Sample height, 3.55 inches.

TABLE II-21

CONSOLIDATION TEST DATA*
ANAEROBIC REFUSE - DRY

Refuse Size	Paper Content - Percent								
	20 Percent			30 Percent			60 Percent		
	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain %
Fine	1,257	0.90	22.5	1,257	1.10	27.5	1,257	0.90	22.5
	1,902	0.95	23.7	1,902	1.20	30.0	1,902	1.05	26.3
	3,123	1.25	31.0	2,509	1.35	33.8	2,509	1.15	28.8
	4,046	1.35	33.8	3,115	1.40	35.0	3,115	1.25	31.3
				4,047	1.50	37.5	4,047	1.45	36.2
Mixed	1,257 (1)	1.00	27.4	1,257 (2)	0.80	21.3	1,257	1.35	33.8
	1,902	1.05	28.8	1,561	0.85	22.7	1,902	1.55	38.8
	2,819	1.20	32.9	2,182	0.95	25.3	2,509	1.75	43.8
	3,426	1.25	34.3	2,803	1.10	29.3	3,115	1.90	47.5
	4,047	1.35	37.0	3,403	1.20	32.0	4,047	2.05	51.3
Coarse	1,257	0.85	21.3	1,257	1.15	28.8	1,257 (3)	1.00	23.5
	1,902	1.10	27.5	1,902	1.40	35.0	1,902	1.30	30.6
	2,509	1.20	30.0	2,509	1.55	38.8	2,819	1.55	36.5
	3,115	1.30	32.5	3,115	1.60	40.0	3,426	1.60	37.6
	4,047	1.45	36.3	4,047	1.80	45.0	4,047	1.75	41.2

NOTES:
(1) Sample height, 3.65 inches.
(2) Sample height, 3.75 inches.
(3) Sample height, 4.25 inches.
* Unwetted, see Table II-12.

TABLE II-22

CONSOLIDATION TEST DATA
ANAEROBIC REFUSE - 65 PERCENT SATURATED

Refuse Size	Paper Content - Percent								
	20 Percent			30 Percent			60 Percent		
	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain %
Fine	1,257	1.10	27.5	1,257	1.20	30.0			
	1,902	1.20	30.0	1,902	1.40	35.0			
	2,509	1.35	33.8	2,509	1.45	36.3			
	3,115	1.43	35.8	3,115	1.60	40.0			
	4,047	1.55	38.8	4,047	1.60	40.0			
Mixed	1,257	1.20	30.0	1,257	1.20	30.0			
	2,509	1.40	35.0	1,902	1.50	37.5			
	3,115	1.55	38.8	2,509	1.65	41.3			
				3,115	1.75	43.8			
	4,047	1.70	42.5	4,047	1.80	45.0			
Coarse	1,257(1)	1.55	34.4	1,257(2)	1.35	32.1	1,257	1.20	30.0
	1,902	1.75	38.9	1,902	1.60	38.1	1,902	1.30	32.5
	2,509	1.95	43.3	2,509	1.70	40.5	2,509	1.40	35.0
	3,115	2.00	44.4	3,115	1.85	44.0	3,115	1.60	40.0
	4,047	2.15	47.8	4,047	1.90	45.2	4,047	1.65	41.3

NOTES: (1) Sample height, 4.5 inches.
(2) Sample height, 4.2 inches.

TABLE II-23

CONSOLIDATION TEST DATA
ANAEROBIC REFUSE - SATURATED

Refuse Size	Paper Content - Percent								
	20 Percent			30 Percent			60 Percent		
	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain, %	Stress, lb/ft^2	Strain, Inch	Strain %
Fine	1,257(1)			1,257	1.25	31.3			
	1,902	1.3	31.7	1,902	1.35	33.8			
	2,509	1.4	34.1	2,509	1.45	36.3			
	3,115	1.5	36.6	3,115	1.55	38.8			
	4,047	1.55	37.8	4,047	1.65	41.3			
Mixed	1,257	1.20	30.0	1,257(2)	1.20	31.2			
	2,509	1.40	34.0	1,879	1.25	32.5			
	3,115	1.55	38.7	2,501	1.25	32.5			
	4,047	1.70	42.5	4,047	1.30	33.8			
Coarse	1,257	1.2	30.0	1,257	1.2	30.0			
	1,902	1.3	32.5	2,205	1.37	34.2			
	2,509	1.5	37.5	3,115	1.59	39.7			
	3,115	1.5	37.5	4,047	1.79	44.8			
	4,047	1.6	40.0						

NOTES: (1) Sample height, 4.10 inches.
(2) Sample height, 3.25 inches.

TABLE II-24

UNIT WEIGHT OF AEROBIC REFUSE AFTER CONSOLIDATION

Refuse Size	Fine						Mixed						Coarse					
Paper Content Percent	20		30		60		20		30		60		20		30		60	
	P	γ	P	γ	P	γ	P	γ	P	γ	P	γ	P	γ	P	γ	P	γ
Dry *	0	60.8	0	41.7	0	29.9	0	69.3	0	34.6	0	23.6	0	70.0	0	42.0	0	20.5
	1,257	78.5	1,257	57.5	1,257	38.6	1,257	95.5	1,257	44.0	1,257	35.6	1,257	89.0	1,257	59.0	1,257	26.8
	1,902	79.8	1,902	59.5	1,902	40.6	1,902	97.5	1,561	44.8	1,902	38.5	1,902	96.5	1,902	64.7	1,902	29.5
	3,123	88.0	2,509	63.0	2,509	42.0	2,819	103.0	2,181	46.3	2,509	42.0	2,509	100.0	2,509	68.7	2,819	32.3
	4,046	92.0	3,115	64.0	3,115	43.5	3,426	105.5	2,803	49.0	3,115	45.0	3,115	104.0	3,115	70.0	3,426	32.8
			4,047	66.7	4,047	46.8	4,047	110.0	3,403	51.0	4,047	48.5	4,047	110.0	4,047	76.4	4,047	34.9
~ 65 Percent Saturated	0	78.7	0	58.2			0	66.0	0	68.0			0	69.4	0	76.2	0	58.0
	1,257	108.5	1,257	83.2			1,257	94.3	1,257	97.2			1,257	105.6	1,257	112.0	1,257	82.8
	1,902	112.5	1,902	89.5			2,509	105.5	1,902	109.0			1,902	113.0	1,902	123.0	1,902	86.0
	2,509	119.0	2,509	91.4			3,115	108.0	2,509	116.0			2,509	122.0	2,509	128.0	2,509	89.3
	3,115	122.5	3,115	97.0			4,047	115.0	3,115	121.0			3,115	125.0	3,115	136.0	3,115	96.7
	4,047	129.6	4,047	97.0					4,047	123.5			4,047	133.0	4,047	139.0	4,047	99.0
~ 100 Percent Saturated	0	57.7	0	69.7			0	72.6	0	64.3			0	82.8	0	73.5		
	1,257	-	1,257	101.0			1,257	103.6	1,257	93.6			1,257	118.0	1,257	105.0		
	1,902	84.5	1,902	105.0			2,509	110.0	1,879	95.3			1,902	122.5	2,205	112.0		
	2,509	87.6	2,509	109.0			3,115	118.0	2,501	95.3			2,509	132.0	3,115	122.0		
	3,115	91.0	3,115	114.0			4,047	126.0	4,047	97.2			3,115	132.0	4,047	133.0		
	4,047	92.7	4,047	118.5									4,047	138.0				

NOTES: (1) P = stress, lb/sq ft.

(2) γ = cell unit weight, lb/cu ft.

* Unwetted, see Table II-12.

TABLE II-25

UNIT WEIGHT OF ANAEROBIC REFUSE AFTER CONSOLIDATION

Refuse Size	Fine						Mixed						Coarse					
Paper Content Percent	20		30		60		20		30		60		20		30		60	
	P	γ	P	γ	P	γ	P	γ	P	γ	P	γ	P	γ	P	γ	P	γ
Dry *	0	49.6	0	33.0	0	25.2	0	58.5	0	58.2	0	24.3	0	53.0	0	38.7	0	19.25
	1,257	66.1	1,257	44.0	1,257	31.5	1,257	73.0	1,257	67.5	1,257	30.4	1,257	82.8	1,257	55.3	1,257	22.3
	2,212	69.5	1,902	44.7	1,902	34.2	1,902	75.7	1,902	83.2	2,205	33.5	1,902	86.8	1,902	61.7	1,864	23.0
	3,130	73.5	3,115	49.0	2,509	34.8	2,819	80.5	2,819	91.2	2,812	35.4	2,509	91.3	2,509	61.7	2,478	24.4
	4,047	76.3	4,047	51.5	3,426	36.7	4,047	85.8	3,426	92.4	3,426	37.4	3,426	94.7	3,426	64.2	3,090	24.8
	-	-	-	-	4,046	38.0	-	-	4,047	95.5	4,047	38.1	4,046	100.0	4,047	66.9	3,403	25.2
~ 65 Percent Saturated	0	57.5	0	87.8			0	63.7	0	75.5			0	66.9	0	67.4	0	50.4
	1,257	80.7	1,257	113.0			1,257	91.1	1,257	116.0			1,257	101.0	1,257	98.0	1,257	73.2
	1,902	85.2	1,902	119.0			1,879	94.4	1,902	120.8			1,902	108.4	1,902	103.6	2,212	77.5
	2,509	88.5	2,509	123.5			2,507	98.0	2,509	128.4			2,509	110.0	2,509	112.2	3,130	80.6
	3,115	92.0	3,123	128.3			3,121	98.0	3,115	134.0			3,115	113.0	3,115	114.5	4,047	85.7
	4,047	98.3	4,047	131.0			3,721	104.0	4,047	137.2			4,047	118.4	4,047	119.6	-	-
	-	-	-	-			-	-	-	-			-	-	-	-	-	-

NOTES: (1) P = stress, lb/sq ft.

(2) γ = cell unit weight, lb/cu ft.

* Unwetted, see Table II-12.

TABLE II-26

TIME - DEFORMATION DATA

Stress, lb/sq ft									
1,257		1,575		2,205		3,115		4,050	
Time sec.	Strain inches	Time sec.	Strain inches	Time sec.	Strain inches	Time sec.	Strain inches	Time sec.	Strain inches
0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
3	0.870	3	0.020	3	0.040	11	0.130	2	0.040
6	0.932	7	0.022	5	0.042	15	0.135	9	0.045
11	1.000	19	0.030	8	0.050	20	0.140	15	0.060
15	1.030	27	0.040	11	0.060	30	0.149	20	0.065
21	1.060	42	0.040	15	0.070	37	0.160	33	0.070
27	1.070	79	0.060	19	0.075	41	0.166	60	0.100
33	1.086			24	0.080	51	0.175	90	0.120
37	1.090			30	0.090	58	0.180	300	0.140
47	1.109			42	0.100	69	0.186	480	0.160
60	1.110			45	0.105	92	0.200	1,080	0.200
75	1.125			53	0.110	105	0.210	1,800	0.220
90	1.140			60	0.120	135	0.220	72,000	0.290
120	1.160			75	0.125				
150	1.170			90	0.130				
360	1.180			105	0.140				
420	1.195			122	0.150				
630	1.200			150	0.160				
710	1.215								

NOTES: Initial sample height, 4.0 inches.

Sample Characteristics: Coarse - 30% paper - 100% saturated - anaerobic.

TABLE II-26 (Cont'd)

TIME - DEFORMATION DATA

Stress, lb/sq ft					
1,257		2,210		3,940	
Time sec.	Strain inches	Time sec.	Strain inches	Time sec.	Strain inches
0	0.0	0	0.0	3	0.0
3	0.575	3	0.055	9	0.065
7	0.640	7	0.060	15	0.071
13	0.645	15	0.075	30	0.080
17	0.650	28	0.080	60	0.090
21	0.660	40	0.085	120	0.108
27	0.665	58	0.090	195	0.120
32	0.670	83	0.100	360	0.125
42	0.675	113	0.110	930	0.160
54	0.685	155	0.115	1,500	0.170
71	0.690	195	0.120	3,625	0.190
87	0.695	600	0.140		
110	0.705	900	0.150		
133	0.710	2,040	0.170		
187	0.715				
294	0.730				
420	0.735				
522	0.740				
1,320	0.765				
2,220	0.780				
4,800	0.800				
5,700	0.810				

NOTES: Initial sample height, 4.0 inches.

Sample characteristics: Coarse - 60% paper - 30% water added by weight - anaerobic.

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TABLE II-26 (Cont'd)

TIME - DEFORMATION DATA

Stress, lb/sq ft					
1,257		2,990		3,890	
Time sec.	Strain inches	Time sec.	Strain inches	Time sec.	Strain inches
0	0.0	0	0.0	0	0.0
5	0.860	5	0.225	5	0.041
9	0.910	10	0.260	13	0.055
12	0.940	15	0.275	20	0.060
17	0.950	30	0.290	30	0.062
23	0.965	45	0.300	45	0.065
30	0.970	60	0.310	60	0.070
40	0.982	90	0.320	120	0.071
60	1.000	120	0.330	180	0.080
75	1.010	180	0.345	300	0.081
120	1.020	300	0.356	600	0.100
150	1.030	900	0.390	1,200	0.102
180	1.035	2,700	0.415	1,800	0.110
300	1.050	3,600	0.420		
1,020	1.080				
1,800	1.100				
3,600	1.110				

NOTES: Initial sample height, 4.0 inches.

Sample Characteristics: Coarse - 20% paper - 30% water added by weight - aerobic.

TABLE II-27

TIME - DEFORMATION DATA

Stress, lb/sq ft					
1,257		2,990		3,900	
Time sec.	Strain inches	Time sec.	Strain inches	Time sec.	Strain inches
0	0.0	0	0.0		
3	0.710	3	0.210	3,600	0.36
9	0.735	5	0.220		
15	0.750	9	0.230		
20	0.760	12	0.240		
27	0.760	18	0.250		
42	0.772	30	0.260		
54	0.780	36	0.265		
75	0.790	44	0.270		
120	0.805	71	0.285		
180	0.820	90	0.290		
5,100	0.880	150	0.295		
		300	0.310		

NOTES: Initial sample height, 4.0 inches.

Sample Characteristics: Coarse - 30% paper - 30% water added by weight - aerobic.

TABLE II-27 (Cont'd)

TIME - DEFORMATION DATA

Stress, lb/sq ft							
1,260		2,990		3,885		4,770	
Time sec.	Strain inches	Time sec.	Strain inches	Time sec.	Strain inches	Time sec.	Strain inches
0	0.0	0	0.0	0	0.0	0	0.0
3	0.830	3	0.256	7	0.055	9	0.335
9	0.850	7	0.282	21	0.060	15	0.385
15	0.870	11	0.290	60	0.062	30	0.415
21	0.875	15	0.300	120	0.070	60	0.455
27	0.880	20	0.302	480	0.080	120	0.500
34	0.890	30	0.315	900	0.082	300	0.580
50	0.895	40	0.320	1,800	0.090	900	0.680
63	0.900	60	0.330	4,500	0.100	1,800	0.780
87	0.910	90	0.340			2,700	0.830
120	0.915	120	0.345				
150	0.920	180	0.355				
255	0.932	1,200	0.395				
480	0.945	2,100	0.405				
900	0.955						

NOTES: Initial sample height, 4.0 inches.

Sample Characteristics: Coarse - 20% paper - 30% water added by weight - anaerobic.

TABLE II-27 (Cont'd)

TIME - DEFORMATION DATA

Stress, lb/sq ft					
1,257		2,990		3,960	
Time sec.	Strain inches	Time sec.	Strain inches	Time sec.	Strain inches
0	0.0	0	0.0	0	0.0
7	0.140	3	0.255	5	0.070
15	0.165	13	0.290	15	0.080
30	0.170	23	0.300	45	0.085
60	0.180	45	0.310	90	0.090
90	0.185	65	0.320	150	0.100
120	0.190	120	0.332	300	0.110
180	0.195	180	0.340	600	0.120
300	0.200	300	0.352	1,200	0.125
600	0.210	600	0.366		
1,200	0.220	1,200	0.380		
1,800	0.230	4,800	0.415		
3,600	0.250				

NOTES: Initial sample height, 4.0 inches.

Sample Characteristics: Coarse - 60% paper - 30% water added by weight - aerobic.

TABLE II-27 (Cont'd)

TIME - DEFORMATION DATA

Stress, lb/sq ft			
1,257		2,990	
Time sec.	Strain inches	Time sec.	Strain inches
0	0.0	0	0.0
3	0.540	3	0.210
5	0.570	7	0.240
10	0.580	11	0.246
15	0.585	15	0.260
20	0.592	30	0.271
30	0.600	45	0.280
45	0.610	60	0.288
60	0.612	120	0.290
90	0.615	180	0.300
120	0.620	300	0.330
180	0.621		
300	0.630		
600	0.640		
1,200	0.642		
2,400	0.652		
3,600	0.658		

NOTES: Initial sample height, 4.0 inches.

Sample Characteristics: Coarse - 30% paper - 30% water added by weight - anaerobic.

TABLE II-28

CONSTANTS FOR EQUATION OF SECONDARY COMPACTION

Type of Cell	Size of Material	Percent Paper	Value of k_s
Aerobic-dry	F	20	13.4
		30	13.4
		60	14.4
	M	20	14.8
		30	12.9
		60	17.1
	C	20	14.8
		30	14.9
		60	13.1
Anaerobic-dry	F	20	11.2
		30	12.5
		60	11.2
	M	20	13.4
		30	11.8
		60	22.5
	C	20	12.7
		30	18.6
		60	19.6
Aerobic-65% saturated	F	20	15.6
		30	12.3
	M	20	12.6
		30	14.5
	C	20	14.1
		30	16.1
		60	13.6
Anaerobic-65% saturated	F	20	13.1
		30	15.0
	M	20	14.3
		30	14.9
	C	20	17.3
		30	15.0
		60	14.8
Anaerobic-saturated	F	20	11.5
		30	14.5
	M	20	
		30	3.2
	C	20	12.2
		30	15.2

NOTE: $C_s = k_s \ln (p/p_o)$

C_s = % secondary compaction

p_o = 1,250 lb/sq ft

k_s = constant

TABLE II-29

PREDICTION OF LANDFILL SUBSIDENCE
SIMULATED LANDFILL

Lift	Age of Fill (Years)	Time after Lift Emplacement (Years)	Overburden Pressure (lb/sq ft)	Increments (lb/sq ft)	Components (%)			S_L (%)	Elevation at top of Lift (ft)
					S_D	C_i	C_s		
1 (Bottom)	0	0	300	+300,+300	0	25	0	25.0	502.25
	1/2	1/2	900	+300,+300,-75	18.6	25	0	39.0	501.83
	1	1	1,425	-75	37.6	25	1.9	54.2	501.37
	1 1/2	1 1/2	1,350		40.0	25	1.1	55.5	501.34
	2	2	1,350		41.4		1.1	56.7	501.30
	2 1/2	2 1/2	1,350	+2,000	41.4	25	1.1	56.7	501.30
	3	3	3,350		41.4	25	13.7	62.1	501.14
2 (Middle)	1/2	0	300	+300,+300	0	25	0	25.0	507.08
	1	1/2	900	-75	18.6	25	0	39.0	506.20
	1 1/2	1	825		37.6	25	0	54.8	505.70
	2	1 1/2	825		40.0	25	0	56.2	505.61
	2 1/2	2	825	+2,000	41.4	25	0	56.2	505.61
	3	2 1/2	2,825		41.4	25	11.6	61.2	505.17
3 (Top)	1	0	300		0	25	0	25.0	511.45
	1 1/2	1/2	300		18.6	25	0	39.0	510.53
	2	1	300		37.6	25	0	54.8	509.97
	2 1/2	1 1/2	300	+2,000	40.0	25	0	56.2	509.92
	3	2	2,300		41.4	25	8.7	59.8	509.38

Assumptions: (1) Three three-ft lifts of partially-saturated refuse emplaced at 180-day intervals and compacted @ 1,250 lb/sq ft.
(2) Average subsidence rate at 180 days: 72%/year.
(3) Average weight loss in each lift: 25% in first six months; nil thereafter.
(4) Elevation at base of fill: assume 500.00 ft.
(5) In-place fill density: assume 100 lb/cu ft.
(6) Each lift covered with an overburden of 300 lb/sq ft.
(7) After three years an overburden of 2,000 lb/sq ft is added.

TABLE III-1

SITE 6 METHANE CONCENTRATIONS
27 AUGUST 1969

(Percent by Volume)

Probe	Percent CH_4
17	0
18	13.2
19	2.4
20	10.0
21	13.7
22	30.3
23	9.8
24	0
25	0
26	0
27	53.5
28	2.4
29	0
30	0
31	0
32	41.0
33	0.7

TABLE III-2

DIFFUSION-DISPERSION COEFFICIENTS FOR METHANE IN VARIOUS POROUS MEDIA

(Soils Tested in 1967)
D (cm^2 per second)

Porous Media	Moisture Content							
	Air Dry				Optimum			
	In Flow Gas Pressure							
	0.25 in H_2O	4.0 in H_2O	12.0 in H_2O	Compaction Percent	4.25 psi	5.0 psi	20 psi	Compaction Percent
Sand	0.0575	0.578	4.58	72	-	-	-	-
Sandy Silt	0.0317	0.152	0.239	62	0.033	0.035	-	84
Silty Clay	0.026	0.088	0.093	67	N.D.F.	N.D.F.	0.026	90
Kaolin Clay	N.F.	N.F.	0.012×10^{-3}	41	N.D.F.	N.D.F.	0.012×10^{-3}	90

psi = 27.673 inches of H_2O (4°C)

N.F. = no detectable flow

TABLE III-3

DIFFUSION-DISPERSION COEFFICIENT FOR METHANE THROUGH SILTY CLAY SOIL

(Soil Tested in 1968)
D (cm^2 Per Second)

Porous Medium	Moisture Content					
	Field Condition(1) (20 percent)			Optimum (2) (28 percent)		
	Inflow Gas Pressure					
	4 in H_2O	12 in H_2O	24 in H_2O	4 in H_2O	12 in H_2O	24 in H_2O
Sand, Silty Clay	0.224	0.282	0.690	0.20	0.236	0.296

(1) Percent compaction = 77
(2) Percent compaction = 87

TABLE III-4

SITE 1 CONTROL SYSTEM
1969 TEST 1
METHANE CONCENTRATIONS

(Percent by Volume)

Sample Point	Before Test 3/25	3/26	3/27	3/28	Static Pressure (inches of water) 3/25
Well					
1A	40		40	42	+0.08
1B	40		34	37	+0.10
1C	37		44	37	+0.10
2A	42		29	46	0
2B	38		39	37	0
2C	49		33	33	0
3A	50		50	46	+0.08
3B	40		41	35	+0.08
3C	46		55	40	+0.07
4A	32		100	47	0
4B	35		56	39	0
4C	35		47	40	0
5A	48	52	50	37	+0.05
5B	42	46	49	45	+0.07
5C	32	55	60	33	+0.06
Probe					
3	17	14	17	18	
7	34	36	37	36	
8	48	56	36	41	
9	37	28	38	37	
13	38	35	40	42	
14	27	31	35	35	
15	--	13	13	18	
16	18	18	23	20	
17	10	10	12	8	
18	14	20	15	19	
19	32	26	39	39	
22	37	49	39	28	
23	29	22	20	29	
24	12	15	17	14	
29	26	36	37	24	
31	20	13	19	14	
32	38	42	39	33	
45	10	10	15	10	
52	14	7	9	8	
55	28	34	33	30	
56	44	40	30	27	
63	30	42	33	39	

TABLE III-5

SITE 1 CONTROL SYSTEM
1969 TEST 2
METHANE CONCENTRATIONS

(Percent by Volume)

Sample Point	4/1 AM	4/2 AM	4/2 PM	4/3 AM	4/3 PM	4/4 AM	4/4 PM	Static Pressure (In. of Water) 4/1	4/2	4/3	4/4
Well											
1A	39	48	20	46	0	52	4	-0.23	-0.26	-0.25	-0.27
1B	39	44	9	51	9	42	0	-0.23	-0.30	-0.24	-0.27
1C	44	44	19	46	5	42	10	-0.20	-0.25	-0.27	-0.30
2A	36	55	32	61	17	43	NR	-0.44	-0.60	-0.65	-0.55
2B	38	38	19	35	10	34	NR	-0.44	-0.50	-0.50	-0.46
2C	38	44	9	59	0	49	NR	-0.33	-0.40	-0.45	-0.45
3A	45	47	30	48	32	38	NR	-5.0	-5.0	-5.0	-5.0
3B	42	20	0	22	0	19	NR	-1.9	-2.0	-2.0	-2.0
3C	28	30	0	21	4	26	NR	-1.2	-1.2	-1.2	-1.1
4A	40	46	30	46	13	45	NR	-0.60	-0.75	-0.70	-0.70
4B	36	34	0	30	0	30	NR	-0.60	-0.72	-0.65	-0.75
4C	31	42	44	51	41	43	NR	-0.38	-0.47	-0.43	-0.46
5A	40	40	24	43	10	32	NR	-0.1[illegible]	-0.20	-0.20	-0.19
5B	47	42	10	52	0	43	NR	-0.06	-0.19	-0.20	-0.19
5C	37	34	20	37	14	28	NR	-0.08	-0.18	-0.19	-0.20
Probe											
3	23	17	5	22	0	24	5				
7	36	32	32	43	39	38	31				
8	42	34	32	42	31	40	35				
9	34	39	35	47	35	44	45				
13	41	32	15	31	0	27	12				
14	38	33	4	37	0	29	7				
15	19	23	30	22	22	17	10				
16	22	20	11	19	7	18	10				
17	12	11	9	12	0	12	17				
18	18	16	13	20	22	20	10				
19	31	14	0	7	0	11	0				
22	32	41	0	37	0	37	0				
23	26	22	8	30	8	32	0				
24	11	11	6	0	0	8	0				
29	29	29	35	34	30	32	15				
31	15	17	20	14	10	18	9				
32	36	38	25	36	10	42	7				
45	10	18	14	12	9	8	19				
52	7	7	25	10	7	9	15				
55	33	34	31	35	30	36	40				
56	34	36	34	42	35	34	40				
63	42	34	40	46	40	40	48				

AM = Reading before pump on

PM = Reading after pump off

TABLE III-6

SITE 1 CONTROL SYSTEM
1969 TEST 3
METHANE CONCENTRATIONS

(Percent by Volume)

Sample Point	Before Test	Blower On			Blower Off			Static Pressure (Inches of Water) Blower Off	Blower On	
	4/7	4/8	4/9	4/10	4/11	4/14	4/15	4/7	4/8	4/9
Well										
1A	48	0	0	0	51	45	42	+0.04	-0.30	-0.40
1B	50	0	0	0	50	39	45	+0.06	-0.34	-0.38
1C	67	8	4	5	47	55	50	+0.04	-0.30	-0.35
2A	62	0	0	0	39	43	40	+0.05	-0.65	-0.60
2B	40	17	25	11	30	45	40	+0.05	-0.55	-0.50
2C	80	0	0	0	51	65	50	+0.04	-0.49	-0.50
3A	51	0	0	0	55	45	43	0	-5.0	-5.0
3B	48	0	0	0	42	50	40	+0.02	-2.0	-2.1
3C	39	2	3	7	30	49	40	+0.02	-1.3	-1.2
4A	47	0	0	0	50	52	46	+0.04	-0.80	-0.75
4B	53	0	0	0	50	50	50	+0.06	-0.80	-0.65
4C	64	0	0	0	60	49	44	+0.04	-0.50	-0.50
5A	48	0	0	0	57	50	42	+0.02	-0.23	-0.26
5B	57	0	0	0	55	54	41	+0.04	-0.25	-0.28
5C	45	7	0	0	35	39	30	+0.03	-0.25	-0.29
Probe										
3	11	0	3	15	7	10	13			
7	30	35	32	25	40	40	35			
8	25	27	19	18	35	32	36			
9	35	20	22	16	21	32	34			
13	30	0	0	0	0	11	15			
14	21	0	0	0	7	15	15			
15	12	3	0	0	0	20	20			
16	10	0	0	0	0	11	20			
17	10	0	0	0	0	14	11			
18	18	10	4	7	11	19	21			
19	35	0	0	0	0	19	22			
22	44	0	0	0	21	29	30			
23	17	0	0	0	10	16	12			
24	3	3	0	2	3	11	7			
29	28	15	15	16	25	36	24			
31	6	17	15	15	26	14	11			
32	55	0	0	0	14	20	25			
45	11	10	10	10	11	16	11			
52	16	5	1	4	8	10	18			
55	31	20	11	30	34	37	32			
56	35	17	17	30	32	42	25			
63	46	30	34	35	37	35	32			

TABLE III-7

SITE 1 CONTROL SYSTEM
1969 TEST 4
METHANE CONCENTRATIONS

(Percent by Volume)

Sample Point	Before Test 4/16	Blower On 4/17	Blower On 4/18	Static Pressure (Inches of Water) 4/17	Static Pressure (Inches of Water) 4/18
Well					
1A	40	30	45	+0.06	+0.05
1B	40	28	40	+0.04	+0.06
1C	42	27	40	+0.05	+0.06
2A	40	0	0	0	+0.01
2B	42	29	35	+0.01	+0.04
2C	45	21	28	+0.01	+0.04
3A	45	19	11	-0.50	-0.47
3B	45	14	12	-0.23	-0.20
3C	49	25	27	-0.12	-0.08
4A	40	25	22	-0.02	-0.01
4B	45	20	11	-0.01	+0.01
4C	40	0	0	-0.01	+0.01
5A	40	38	35	+0.02	+0.04
5B	40	35	35	+0.02	+0.06
5C	33	38	45	+0.02	+0.07
Probe					
3	10	14	14		
7	14	35	30		
8	18	38	21		
9	25	30	25		
13	20	17	12		
14	20	15	16		
15	24	20	21		
16	20	19	30		
17	17	13	22		
18	14	19	20		
19	23	10	9		
22	30	19	22		
23	18	17	15		
24	7	5	7		
29	20	23	20		
31	--	--	--		
32	25	18	25		
45	20	11	13		
52	5	12	19		
55	14	35	33		
56	30	20	28		
63	37	28	26		

TABLE III-8

SITE 1 CONTROL SYSTEM
1969 TEST 5
METHANE CONCENTRATIONS

(Percent by Volume)

						Static Preesure (In. of Water)			
	Before				Blower	Blower			
Sample	Test		Blower On		Off	Off		Blower On	
Point	4/21	4/22	4/23	4/24	4/25	4/21	4/22	4/23	4/24
Well									
1A	40	0	0	0	37	+0.08	-0.20	-0.20	-0.19
1B	45	0	0	0	33	+0.10	-0.20	-0.23	-0.22
1C	35	5	3	0	20	+0.09	-0.20	-0.27	-0.21
2A	42	--	--	0	30	+0.10	-0.40	-0.40	-0.40
2B	45	--	--	0	15	+0.09	-0.33	-0.39	-0.35
2C	55	--	--	0	38	+0.09	-0.30	-0.30	-0.30
3A	47	--	--	15	30	+0.05	-3.40	-3.60	-3.40
3B	47	--	--	0	30	+0.07	-1.40	-1.40	-1.40
3C	47	--	--	4	45	+0.08	-0.90	-0.85	-0.85
4A	50	--	--	0	40	+0.09	-0.50	-0.50	-0.45
4B	40	--	--	0	40	+0.10	-0.45	-0.49	-0.49
4C	50	--	--	0	45	+0.07	-0.30	-0.37	-0.32
5A	42	0	0	0	35	+0.08	-0.15	-0.15	-0.17
5B	47	0	1	0	35	+0.08	-0.15	-0.17	-0.15
5C	52	4	12	0	30	+0.10	-0.15	-0.12	-0.17
Probe									
3	17	9	7	0	10				
7	30	38	28	8	22				
8	35	25	16	40	14				
9	27	35	14	39	20				
13	22	0	0	0	0				
14	27	0	0	0	5				
15	15	10	0	0	0				
16	33	0	0	0	0				
17	18	0	0	0	0				
18	21	25	10	3	10				
19	27	0	0	0	0				
22	26	0	0	0	14				
23	30	0	0	0	0				
24	4	2	0	0	0				
29	36	14	12	14	14				
31	--	--	--	--	--				
32	32	0	0	0	23				
45	12	14	3	4	15				
52	7	4	0	4	3				
55	32	34	30	12	15				
56	30	20	0	0	0				
63	32	45	42	11	30				

TABLE III-9

SITE 1 CONTROL SYSTEM
1969 TEST 6
METHANE CONCENTRATIONS

(Percent by Volume)

Sample Point	Blower Off 4/25	4/28	All Well Pipes Open 4/29	5/1	5/5	5/8	5/12	5/16	5/20	5/28	Static Pressure (Inches of Water) Blower On 4/25	4/28
Well												
1A	37	15	13	4	30	36	46	47			-5.0	-5.0
1B	33	5	20	27	30	38	55	50		52	-1.5	-2.0
1C	20	8	32	36	30	35	44	50	50		-1.1	-1.5
2A	30	2	0	0	0	17	23	34			-0.70	-0.90
2B	15	6	20	31	29	30	40	55		55	-0.55	-0.75
2C	38	0	31	29	23	30	45	65	47	47	-0.45	-0.60
3A	30	0	0	0	0	25	40	45			-0.27	-0.40
3B	30	0	18	34	25	39	46	50		60	-0.30	-0.45
3C	45	11	15	20	27	35	32	35	40	30	-0.22	-0.35
4A	40	0	0	0	5	20	40	47			-0.10	-0.26
4B	40	0	16	35	30	30	44	55			-0.12	-0.26
4C	45	3	19	30	27	30	37	38	37	55	-0.10	-0.20
5A	35	0	0	24	35	33	49	50	37		-0.02	-0.09
5B	35	0	26	34	35	39	44	50	42		-0.02	-0.09
5C	30	0	16	29	17	32	45	50	38	60	-0.03	-0.06
Probe												
3	10	-	-	17	-	-	-	-	-	-		
7	22	21	27	38	15	29	30	32	37	-		
8	14	16	28	42	15	35	30	35	36	63		
9	20	11	19	32	12	32	32	38	39	60		
13	0	0	0	3	4	9	17	21	12	21		
14	5	0	0	1	0	6	9	20	20	15		
15	0	0	0	0	0	0	3	5	5	5		
16	0	0	0	0	0	0	0	0	Tr	0		
17	0	0	0	0	0	0	0	Tr	Tr	Tr		
18	10	-	10	15	-	18	16	20	17	24		
19	0	0	0	0	3	3	10	23	28	18		
22	14	0	14	18	6	20	15	25	-	-		
23	0	0	0	7	-	30	23	15	-	-		
24	0	-	-	13	-	25	-	-	-	-		
29	14	-	16	28	-	29	26	30	-	-		
31	-	-	-	9	-	-	20	12	-	-		
32	23	0	0	4	4	7	11	19	23	15		
45	15	8	18	10	8	7	7	12	-	-		
52	3	0	7	5	3	4	5	5	-	-		
55	15	12	20	40	17	28	27	32	-	-		
56	0	0	16	39	20	25	23	28	30	-		
63	30	0	0	16	10	20	23	32	37	43		

Note: All readings made using a J.W. Sniffer

TR = Trace

TABLE III-10

SITE 1 CONTROL SYSTEM
1969 TEST 7
METHANE CONCENTRATIONS

(Percent by Volume)

Sample		6/10 Blower off Time	6/11 Blower on Time					6/12 Blower off Time					6/17 Blower off Time	6/23 Time
Point	-	1050	1145	1215	1245	1315	1345	1430	0845	0940	1020	1100	1045	1030
Well														
1A	43												19	28
1B	42												5	5
1C	44												10	8
2A	40												22	29
2B	40												14	16
2C	39												28	40
3A	40												40	28
3B	41												28	7
3C	38												42	39
4A	37												27	23
4B	42												5	5
4C	60												45	40
5A	43												21	31
5B	45												5	4
5C	47												6	16
Probe														
3	20												11	18
4	57												43	-
5	33												41	-
6	28												26	-
7	37												29	34
8	42												19	20
9	52	39						46	33			32	17	12
10	35												0	-
11	37												23	-
12	37												4	-
13	27	32						6	0			0	0	0
14	26	26						2	0			1	0	0
15	13	8						6	0			1	0	0
16	4	1						0	0			0	0	0
17	2	0						0	0			0	0	0
18	27	26						19	15			16	11	16
19	31	27	6	5	4	3	2	1	0	0	0	0	0	0
22	32	32	6	0	0	0	0	0	0	0	5	5	4	7
23	22	14	5	5	5	5	4	5	5	4	4	4	0	0
24	17	13	11	10	9	13	11	11	8	13	14	11	0	6
27	24	23						4	2			4	0	0

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TABLE III-10 (Continued)

SITE 1 CONTROL SYSTEM
1969 TEST 7
METHANE CONCENTRATIONS

(Percent by Volume)

Sample		6/10 Blower off Time	6/11 Blower on Time					6/12 Blower off Time					6/17 Blower off Time	6/23 Blower off Time
Point -		1050	1145	1215	1245	1315	1345	1430	0845	0940	1020	1100	1045	1030
29	34	29						18	14			19	19	20
31	10	8						7	7			11	7	11
32	10	28						4	0			1	0	0
34	15												5	-
35	27												28	-
36	25												41	-
45	1												0	-
52	3												1	3
55	4												19	27
56	23												-	-
63	28												13	12

TABLE III-11

SITE 1 CONTROL SYSTEM
1969 TEST 8
METHANE CONCENTRATIONS

(Percent by Volume)

Sample Point	6/23 Blower off Time	6/27 Blower off Time	7/1 Blower off Time	7/10 Blower off Time	7/28 Blower off Time
	1030	1045	1045	1045	1040
Well					
1A	28	26	33		38
1B	5	17	16		19
1C	8	13	11		17
2A	29	32	43		37
2B	16	21	25		12
2C	40	33	40		50
3A	28	34	37		35
3B	7	27	29		30
3C	39	42	40		37
4A	23	29	35		31
4B	5	10	15		12
4C	40	45	50		40
5A	31	37	35		39
5B	4	5	8		10
5C	16	13	22		22
Probe					
3	18	13	10	0	12
4	-		40		48
5	-		37		27
6	-		17		19
7	34	37	35	52	27
8	20	31	24	38	20
9	12	18	12	20	11
10	-		0		0
11	-		11		18
12	-		5		17
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0		0
16	0	0	0	0	0
17	0	0	0	0	0
18	16	17	14	20	17
19	0	0	0	0	0
22	7	4	12	14	2
23	0	0	0	0	0
24	6	6	3	10	5
27	0	3	4	5	0

TABLE III-11 (Continued)

SITE 1 CONTROL SYSTEM
1969 TEST 8
METHANE CONCENTRATIONS

(Percent by Volume)

Sample Point	6/23 Blower off Time 1030	6/27 Blower off Time 1045	7/1 Blower off Time 1045	7/10 Blower off Time 1045	7/28 Blower off Time 1040
29	20	24	16	28	18
31	11	5	10	12	11
32	0	3	3		3
34	-		6		20
35	-		35		20
36	-		45		32
45	-				
52	3				
55	27				
56	-				
63	12	13	15	23	

TABLE III-12

SITE 1 CONTROL SYSTEM
1969 TEST 10
METHANE CONCENTRATIONS

(Percent by Volume)

Sample Point	8/20 Blower off Time 1030	9/3 Blower off Time 1115	9/3 Static Pressure (in of H_2O)
Well			
1A		31	-4.95
1B		7	-1.64
1C		24	-1.23
2A		36	-0.82
2B		33	-0.75
2C		42	-0.68
3A		32	-0.48
3B		12	-0.55
3C		23	-0.58
4A		42	-0.70
4B		21	-0.70
4C		37	-0.65
5A		31	-5.0*
5B		3	-1.8
5C		5	-1.3
Probe			
3	0	0	
4		22	
5		23	
6		21	
7	2	3	
8	0	0	
9	0	0	
10		0	
11		0	
12		0	
13	0	0	
14	0	0	
15	0	0	
16	0	0	
17	0	0	
18	0	0	
19	0	0	
22	0	0	
23	0	0	
24	0	0	
27	0	0	

* Maximum vacuum reading possible by Velometer = -5.0

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TABLE III-12 (Continued)

SITE 1 CONTROL SYSTEM
1969 TEST 10
METHANE CONCENTRATIONS

(Percent by Volume)

Sample Point	8/20 Blower off Time 1030	9/3 Blower off Time 1115	9/3 Static Pressure (in of H_2O)
29	0	0	
31	0	0	
32	0	0	
34		0	
35		0	
36		0	

TABLE III-13

SITE 5 CONTROL SYSTEM GAS ANALYSIS DATA SHEET

(Percent)

Greenhouse Temperature: 65°F Weather: Overcast

Date Sample Taken: 21 May 1969

Date Sample Analyzed: 22 May 1969

Probe	CO_2	O_2	N_2	CH_4
23	22.3	3.7	51.3	20.8
24	7.3	10.8	83.3	0
25A	0	21.2	80.9	0
25B	0	18.0	80.4	0
25D	25.9	4.3	37.1	32.3
26A	Tr	21.4	80.8	0
26B	0.5	19.4	82.0	0
27A	0	22.4	81.9	0
27B	1.0	20.3	82.0	0
27C	43.2	1.9	21.5	36.6
28A	Tr	22.5	81.7	0
28B	Tr	22.5	82.3	0
29A	0	22.6	81.6	0
29B	6.7	15.1	82.5	0
29C	29.1	2.3	49.5	21.6
30	29.5	6.1	43.9	24.8
31	18.7	12.5	54.1	19.1

TABLE III-14

SITE 5 CONTROL SYSTEM
GAS ANALYSIS DATA SHEET

(Percent)

Greenhouse Temperature: 70°F Weather: Clear

Date Sample Taken: 27 August 1969

Date Sample Analyzed: 29 August 1969

Probe	CO_2	O_2	N_2	CH_4
23	7.9	17.8	70.4	3.1
24	9.9	12.5	79.3	0
25A	0	21.3	81.0	0
25B	7.6	12.6	81.4	0
25D	35.3	4.6	27.5	35.6
26A	0	13.9	81.3	0
26B	21.7	2.1	74.5	3.6
27A	Tr	21.8	80.5	0
27B	18.5	1.4	78.7	1.3
27C	Tr	20.9	79.7	0
28A	Tr	21.2	80.0	0
28B	16.1	1.9	81.5	0
29A	Tr	20.8	80.5	0
29B	22.5	1.7	73.0	3.5
29C	36.3	1.6	37.9	25.5

NOTE: Vent pipes in gravel beneath barrier were sealed on 18 August 1969.

TABLE III-15

SITE 5 CONTROL SYSTEM GAS ANALYSIS DATA SHEET

(Percent)

Greenhouse Temperature: 75°F Weather: Warm-Hazy

Date Sample Taken: 8 October 1969

Date Sample Analyzed: 9 October 1969

Probe	CO_2	O_2	N_2	CH_4
23	24.9	1.7	58.3	11.0
24	11.3	8.5	76.7	0
25A	0	16.3	80.6	0
25B	10.9	7.4	78.7	0
25D	41.3	1.8	19.1	37.4
26A	0	20.8	78.8	0
26B	25.0	2.0	55.0	15.0
27A	Tr	20.6	79.1	0
27B	3.1	16.6	73.7	1.7
27C	40.7	1.8	19.9	36.6
28A	Tr	21.5	76.3	0
28B	1.5	18.2	75.9	0.8
29A	0	20.4	77.4	0
29B	26.5	2.5	49.5	20.6
29C	23.3	7.2	47.0	19.1
30	27.3	1.9	47.8	20.1
31	23.3	7.6	44.7	22.2

NOTE: Vent pipes in gravel beneath barrier have been sealed since 18 August 1969.

TABLE III-16

SITE 5 CONTROL SYSTEM GAS ANALYSIS DATA SHEET

(Percent)

Greenhouse Temperature: 75°F Weather: Clear

Date Sample Taken: 16 October 1969

Date Sample Analyzed: 17 October 1969

Probe	CO_2	O_2	N_2	CH_4
23	23.9	1.8	64.8	6.7
24	2.5	16.3	76.9	0
25A	0	20.8	78.2	0
25B	0	20.4	78.1	0
25D	33.7	4.6	28.7	31.4
26A	0	20.7	80.7	0
26B	0.5	19.9	78.7	0
27A	0	21.0	78.6	0
27B	2.1	23.2	78.3	0
27C	10.6	19.1	66.9	8.3
28A	Tr	23.0	77.4	0
28B	0	22.9	77.9	0
29A	Tr	23.8	78.4	0
29B	4.7	20.3	77.4	0
29C	29.7	6.0	46.8	20.0
30	17.2	11.1	65.3	8.3
31	29.9	6.8	35.9	30.9

NOTE: Vent pipes in gravel beneath barrier which had been sealed since 18 August were opened again, allowing ventilation of gravel base, on 8 October 1969.

TABLE III-17

SITE 8 CONTROL SYSTEM
1969 TEST 1
METHANE CONCENTRATIONS

(Percent by Volume)

	9/17 Pre-Test		11/5		12/5	
Probe	Ch	JW	Ch	JW	Ch	JW
2B	-		20.4	37		41
2C	25.0		29.9	23		35
3A	40.3		26.8	22		32
3B	0		0	0		0
6	0		0	0		0
6A	0		0	0		0
7A	42.8		20.4	28		24
7C	44.4		35.8	32		47
8	15.7		10.8	12		23
8B	9.3		8.6	10		25
9C	31.0		7.3	7		28
10	8.4		0	0		0
10A	16.8		0	0		0
13	0		0	0		0
13A			1.4	3		0
13C	0		0	0		0
14A	14.6		20.9	26		32
15A	0		16.4	31		8
16A	0		0	0		0
18B	0		0	0		Lost
19A	0		0	0		0
19B	0		0	0		0
22A	0		0	0		0
23A	0		0	0		0
25	43.7		44.0	50		50
26	40.0		41.8	43		39
27	1.5		0	0		0
28	4.5		6.0	7		3
T-1			14.8	32		57
T-2			41.8	40		45
T-3			52.2	50		46
T-4			44.3	46		53
T-5			42.3	42		32
T-6			33.3	35		41
T-7			1.2	2		14
T-8			0.5	0		11
T-9			2.7	3		7
T-10			0.7	2		6
T-11			14.8	12		22
T-12			11.0	12		20

TABLE III-17 (Continued)

SITE 8 CONTROL SYSTEM
1969 TEST 1
METHANE CONCENTRATIONS

(Percent by Volume)

Probe	9/17 Pre-Test Ch	JW	11/5 Ch	JW	12/5 Ch	JW
T-13			0.6	6		10
T-14			1.2	4		15
W-1			50.4	50		50
W-2			60.0	50		50

NOTE: Ch = Chromatograph

JW = Johnson-Williams Explosion Meter

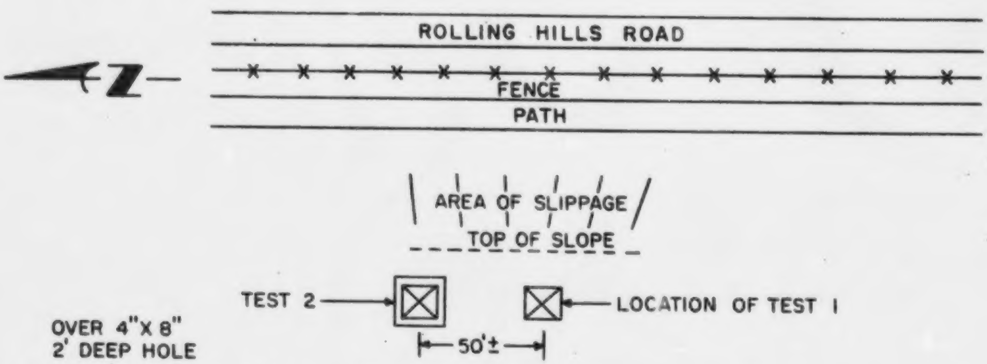
TABLE III-18

GAS EXPLOSION UNIT INSTALLATION DATA

TEST 2

1. Test Site: South Coast Botanic Garden

2. Installation Location:


ROLLING HILLS ROAD
N
FENCE
PATH
AREA OF SLIPPAGE
TOP OF SLOPE
TEST 2
LOCATION OF TEST 1
50'±
OVER 4"X 8" 2' DEEP HOLE

3. Character of Soil: Dry, Fine, Diatomaceous Earth

4. General State of Fill: Test Over Area of Subsidence Problems

5. Weather Prior to Installation: Clear and Warm

6. Weather at Time of Installation: Clear and Warm
Light Breeze Toward West

7. Date of Installation: 1 October 1969

8. Time of Installation: 11:35 A.M.

9. Remarks: Sniffer showed 16% just after installation (All Openings Closed). Hole tested 30% methane concentration prior to installation.

10. Installed By: CWS and MD

TABLE III-18 (Continued)
GAS EXPLOSION UNIT
DETONATION DATA

TEST 2

DATE	TIME	%METHANE			IGNITION POINT			DET'N		CORK HEIGHT		MATCH HEIGHT AT IGNITION	DURATION OF BURNING	REMARKS:
		TOP	MID	BOTTOM	TOP	MID	BOTTOM	SUCCESS	FAILURE	CHIEF OPERATOR	ASSISTANT OPERATOR			
10/1	12:50	44	48	46	X	X	X		X					Cork removed
	12:57	20	--	13	X	X	X		X					Cork replaced for test
	13:05	25	--	--								At top	--	Put out flame w/cork
	13:11	20	--	--	X				X					Replaced cork
	13:13	5	--	7	X				X					
		"		"		X			X					
		"		"			X		X					
		"		"	X	X	X	X						Ignition with cork out
	13:22	4	--	--	X				X					
	13:25	4	5.0	4	X			X		0	0			Rock under bottom edge
														Whole works caught
														on fire; extinguished.
	13:27	--	--	10	X			X	One edge of cork went up 1/2" and stuck					Rock under bottom of box

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TABLE III-19
GAS EXPLOSION UNIT
INSTALLATION DATA

TEST 3

1. Test Site: South Coast Botanic Garden
2. Installation Location:

Same as Test 2

3. Character of Soil: Same as Test 2
4. General State of Fill: Same as Test 2
5. Weather Prior to Installation: Warm and Clear
6. Weather at Time of Installation: Warm and Clear Light Breeze
7. Date of Installation: 8 October 1969
8. Time of Installation: 13:00
9. Remarks: Hole partly filled with dirt
10. Installed By: CWS and MD

TABLE III-19 (Continued)
GAS EXPLOSION UNIT
DETONATION DATA

TEST 3

DATE	TIME	% METHANE TOP	 MID	 BOTTOM	IGNITION POINT TOP	 MID	 BOTTOM	DET'N SUCCESS	 FAILURE	CORK HEIGHT CHIEF OPERATOR	 ASSISTANT OPERATOR	MATCH HEIGHT AT IGNITION	DURATION OF BURNING	REMARKS:
10/8	13:27	22	14	17	X				X					
		"	"	"		X			X					
		"	"	"					X					Cork removed, air wafted
	13:31	5			X			X		3/4"	1"			Sniffer on 10:1
	13:33	4.2			X			X		1"	1"			Dust blew out bottom of box. Sniffer on 1:1
	13:35	4.3			X				X					Sniffer on 1:1
	13:37	5			X				X					Sniffer on 10:1
		"				X			X					
		"					X		X					
	13:39	3.7	2.4	2.3	X				X					
		"	"	"		X			X					
		"	"	"			X	X		0"	0"			Dust blew out of bottom of box
	13:52	14	15	20	X				X					Sniffer on 10:1
						X			X					
							X		X					Cork removed, air wafted

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TABLE III-19 (Continued)
GAS EXPLOSION UNIT
DETONATION DATA

TEST 3

DATE	TIME	% METHANE			IGNITION POINT			DET'N		CORK HEIGHT		MATCH HEIGHT AT IGNITION	DURATION OF BURNING	REMARKS:
		TOP	MID	BOTTOM	TOP	MID	BOTTOM	SUCCESS	FAILURE	CHIEF OPERATOR	ASSISTANT OPERATOR			
10/8	13:54	5			X				X					Cork replaced just before test
	13:57		4.5			X		X		1"	½"			Sniffer on 1:1
	14:00		5.0			X			X					Sniffer on 1:1
	14:02	3.5	3.8	2.7	X	X	X		X					Cork out, replaced after test
	14:05	7			X			X		1½"	1"			Sniffer on 10:1
	14:07			8			X		X					
	14:08	--	--	--	X			X				0	0	
	14:10		4.7			X			X					
					X				X					
							X		X					
					X	X	X		X					
	14:13	16	12	14	X				X					
						X			X					
							X		X					
	14:15		10			X			X					

TABLE III-20

GAS EXPLOSION UNIT
INSTALLATION DATA

TEST 4

1. Test Site: South Coast Botanic Garden
2. Installation Location:
   Same as Test 2
3. Character of Soil: Same
4. General State of Fill: Same
5. Weather Prior to Installation: Clear and Warm
6. Weather at Time of Installation: Clear and Warm
   slight breeze from west
7. Date of Installation: 16 October 1967
8. Time of Installation: 10:45 A.M.
9. Remarks: Bottle samples taken as shown in log.
   Photographs taken this day.
10. Installed By: CWS and MD

TABLE III-20 (Continued)
GAS EXPLOSION UNIT
DETONATION DATA

TEST 4

DATE	TIME	%METHANE			IGNITION POINT			DET'N		CORK HEIGHT		MATCH HEIGHT AT IGNITION	DURATION OF BURNING	REMARKS:
		TOP	MID	BOTTOM	TOP	MID	BOTTOM	SUCCESS	FAILURE	CHIEF OPERATOR	ASSISTANT OPERATOR			
10/16	11:00	15	18	17	X				X					
						X			X					
							X		X					After initial test,
					X	X	X		X					cork removed, air wafted, cork replaced
	11:07	4.0			X			X		1/2"	2"			Delayed reaction
	11:10	4.5			X			X		3/4"	1"			Bottle 21 from top point Delayed reaction
	11:12	5.0			X			X		1"	1"			
	11:15	4.7			X			X		0	0			Dirt blown from around bottom
	11:30	4.6			X			X		1/2"	3/4"			Bottle 22 from mid point
	12:45	3.0			X	X	X		X					Bottle 23 from top strong breeze blown

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TABLE IV-1

COMPOSITION OF SYNTHETIC REFUSE USED IN THE LEACHATE EXPERIMENT

(Percent by Weight)

Ingredient	TR*	RH**
Paper	50	30
Garden waste, wood	10	20
Garbage	10	20
Metals, glass, ceramics	20	20
Leather, rags, plastics	5	5
Dirt, sweepings	5	5
	100	100

* TR = Typical refuse.
** RH = Refuse high in garbage.

TABLE IV-2

MOISTURE AND VOLATILE MATTER CONTENT IN SYNTHETIC REFUSE INGREDIENTS

(Percent)

Ingredient	H_2O	VM
Paper	1.16	>99.3
Garden waste	22.60	83.5
Vegetable waste	96.20	75.3
Rags and plastics	1.04	>99.

TABLE IV-3

MOISTURE AND VOLATILE MATTER CONTENT IN TEST SAMPLES

(Percent)

Sample	H_2O	VM
BR 1-8	83.7 - 102.5	41.5 - 45.5
BR 2-4	69.8 - 72	30.8 - 37.4
CC 1-2	29.5 - 45.0	13.7 - 29.6
CC 2-3	29.4 - 34.2	48.6 - 50.2
Typical Synthetic Refuse*	7.95	69.2**
Synthetic Refuse High in Garbage*	16.1	64.7**

---

* Values were calculated on the basis of percent moisture and volatile matters in ingredients of these samples.

** Since the volatile matter is measured as loss on ignition, the refuse higher in paper seems to have a high VM ratio than the refuse higher in garbage. If the volatile matter is calculated on the basis of garbage and garden wastes only the % VM would be 11.5 and 38.5% respectively.

TABLE IV-4

WEIGHTS OF LEACHED SAMPLES AND VOLUMES OF ADDED WATER

Sample	Series 1			Series 2			Series 3		
	W gms	γ	V_o mls	W gms	γ	V_o mls	W gms	γ	V_o mls
BR 1-8	2,612	0.435	5,500	1,394	0.455	1,700	1,202	0.400	1,800
BR 2-4	1,735	0.289	6,000	926	0.309	1,800	862	0.285	2,000
CC 1-2	2,765	0.461	4,500	1,304	0.434	1,400	1,666	0.555	900
CC 2-3	1,168	0.193	6,300	624	0.208	2,000	560	0.187	2,000
TR	362	0.0603	4,750	208	0.0693	1,710	169	0.0563	1,690
RH	696	0.116	5,500	422	0.141	1,965	296	0.099	2,000

TABLE IV-5

RELATION BETWEEN REFUSE SPECIFIC GRAVITY AND REQUIRED WATER FOR IMMERSION

Sample	Series	Weight	Water Volume Added 10^{-2} ft^3	Water Volume/ lbs Refuse 10^{-2} ft^3/lb	Initial sp. gr. of Refuse γ
BR 1-8	2	3.06	6.00	1.96	0.465
BR 1-8	3	2.64	6.35	2.40	0.400
BR 2-4	2	2.02	6.35	3.14	0.309
BR 2-4	3	1.90	7.05	3.71	0.285
CC 1-2	2	2.87	4.94	1.78	0.434
CC 1-2	3	3.68	3.18	0.865	0.555
CC 2-3	2	1.37	7.06	5.16	0.208
CC 2-3	3	1.23	7.06	5.74	0.187
TR	2	0.458	6.04	13.20	0.0693
TR	3	0.372	5.97	16.00	0.0563
RH	2	0.930	6.94	7.45	0.141
RH	3	0.650	7.06	10.85	0.099

TABLE IV-6

EXPERIMENTAL RESULTS OF SERIES 1 ANALYSIS OF LEACHATE SAMPLES AFTER ONE DAY

	Samples					
Test	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
COD mg/l	2,200	4,150	975	5,970	294	532
Kjeld-N mg/l	214	220	23.8	234	7.0	14.3
Hardness mg/l	235	500	395	1,175	120	230
ALK mg/l	528	961	420	957	58	100
TDS mg/l	3,696	4,260	2,452	3,524	280	635
pH	7.5	7.3	7.4	6.5	6.6	6.4

TABLE IV-7

EXPERIMENTAL RESULTS OF SERIES 1
ANALYSIS OF LEACHATE SAMPLES AFTER EIGHT DAYS

Test	Samples					
	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
COD mg/l	2,815	5,025	1,205	7,450	785	2,140
Kjeld-N mg/l	244	238	22	259	13.3	46.3
Hardness mg/l	380	820	700	1,500	300	512
ALK mg/l	835	1,480	780	1,130	165	290
TDS mg/l	4,215	5,380	2,400	6,965	790	1,990
pH	7.5	6.8	6.9	6.5	5.7	5.4

TABLE IV-8

EXPERIMENTAL RESULTS OF SERIES 1
ANALYSIS OF LEACHATE SAMPLES AFTER 40 DAYS

Test	Samples					
	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
COD mg/l	5,300	9,640	4,520	7,840	662	2,835
Kjeld-N mg/l	235	225	18.2	210	13.0	61.7
Hardness mg/l	1,220	2,300	2,060	2,460	540	806
ALK mg/l	1,850	2,500	2,070	1,870	536	400
TDS mg/l	6,282	8,168	6,076	7,168	2,072	3,124
pH	6.5	5.75	6.30	5.35	7.0	5.15

TABLE IV-9

EXPERIMENTAL RESULTS OF SERIES 2
ANALYSIS OF LEACHATE SAMPLES AFTER ONE DAY

Test	Samples					
	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
COD mg/l	2,060	2,060	717	7,940	385	660
Kjeld-N mg/l	187	160	23.5	305	9.4	18.9
Hardness mg/l	230	350	290	2,300	220	310
ALK mg/l	525	790	378	915	78	136
TDS mg/l	3,056	5,892	2,230	8,045	625	980
pH	7.5	7.4	7.3	6.5	6.5	6.4

TABLE IV-10

EXPERIMENTAL RESULTS OF SERIES 2
ANALYSIS OF LEACHATE SAMPLES AFTER EIGHT DAYS

Test	Samples					
	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
COD mg/l	2,615	3,120	985	8,250	865	2,635
Kjeld-N mg/l	187	155	17	284	16.5	52.6
Hardness mg/l	310	472	530	2,500	362	612
ALK mg/l	719	1,152	660	1,274	162	376
TDS mg/l	3,085	3,345	2,200	7,675	395	1,965
pH	7.4	7.0	7.2	6.7	5.8	5.5

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TABLE IV-11

EXPERIMENTAL RESULTS OF SERIES 2
ANALYSIS OF LEACHATE SAMPLES AFTER 40 DAYS

Test	Samples					
	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
COD mg/l	4,440	5,725	3,590	6,050	1,125	2,450
Kjeld-N mg/l	163	119	13.0	225	16.5	51.5
Hardness mg/l	720	1,780	1,720	2,460	460	705
ALK mg/l	1,450	1,790	1,500	1,600	312	560
TDS mg/l	5,200	6,756	4,976	6,830	1,956	2,928
pH	6.8	6.15	6.4	6.5	5.75	5.35

TABLE IV-12

EXPERIMENTAL RESULTS OF SERIES 3
ANALYSIS OF LEACHATE SAMPLES AFTER ONE DAY

Test	Samples					
	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
Volume drained mls	1,290	1,435	135	1,420	1,200	1,400
COD mg/l	2,590	2,900	2,520	6,860	330	760
Kjeld-N mg/l	205	192	91.6	272	7.3	17.9
Hardness mg/l $CaCO_3$	212	442	600	1,950	140	260
ALK mg/l $CaCO_3$	570	932	593	978	56	112
TDS mg/l	2,992	3,864	3,130	6,888	510	770
pH	7.5	7.4	7.5	6.4	6.4	6.2

TABLE IV-13

EXPERIMENTAL RESULTS OF SERIES 3
ANALYSIS OF LEACHATE SAMPLES AFTER EIGHT DAYS

Test	Samples					
	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
Volume drained mls	1,175	1,310	160	1,255	1,205	1,480
COD mg/l	2,110	2,370	2,010	3,620	432	1,590
Kjeld-N mg/l	135	98	48	121	8.1	84.0
Hardness mg/l $CaCO_3$	280	510	642	960	148	330
ALK mg/l $CaCO_3$	590	785	832	680	104	200
TDS mg/l	1,980	2,500	2,950	3,305	365	950
pH	7.4	6.7	7.5	6.5	6.1	5.5

TABLE IV-14

EXPERIMENTAL RESULTS OF SERIES 3
ANALYSIS OF LEACHATE SAMPLES AFTER 23 DAYS

Test	Samples					
	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
Volume drained mls	1,120	1,235	160	1,100	1,170	1,420
COD mg/l	1,790	2,710	1,940	2,330	345	976
Kjeld-N mg/l	90.5	46.8	42.7	45.8	5.3	21.0
Hardness mg/l	370	770	750	780	150	215
ALK mg/l	718	814	1,118	541	76	95
TDS mg/l	1,805	2,845	2,960	2,295	300	620
pH	6.9	6.2	7.3	6.3	5.7	5.1

TABLE IV-15

EXPERIMENTAL RESULTS OF SERIES 3
ANALYSIS OF LEACHATE SAMPLES AFTER 40 DAYS

Test	BR 1-8	BR 2-4	CC 1-2	CC 2-3	TR	RH
Volume drained mls	1,100	1,200	210	1,075	1,150	1,400
COD mg/l	2,650	3,570	4,280	1,985	284	615
Kjeld-N mg/l	36.4	37.1	28.7	22.8	4.75	16.4
Hardness mg/l $CaCO_3$	1,050	1,420	1,820	820	76	144
ALK mg/l $CaCO_3$	1,040	1,230	1,750	700	43	94
TDS mg/l	3,863	3,805	5,492	2,152	456	1,123
pH	6.45	6.0	6.7	6.25	5.45	5.15

TABLE IV-16

CONCENTRATIONS OF CL, SO_4 AND NO_3 IN LEACHATES FROM SERIES 2 AND 3

Sample	Chlorides mg/l		Sulfates mg/l		Nitrates mg/l	
	Series 2	Series 3	2	3	2	3
BR 1-8	510	710	0	10.0	1.5	2.3
BR 2-4	475	605	0	0	3.25	2.0
CC 1-2	375	560	9	2.0	1.3	1.0
CC 2-3	275	310	336	400	1.9	1.1
TR	75	107	9	44	3.45	0.6
RH	125	128	8	200	0.7	0.5

TABLE IV-17

AMOUNT OF LEACHED MATERIAL
SERIES 1

Sample: BR 1-8
Total Water added V_o: 5,500 mls
Sample wt. W_o: 2,612 gms

	COD	TDS	N	HRD	ALK
Conc. after 1 day, C_{t1}, g/1	2.200	3.696	0.214	0.235	0.528
Amount Leached L_{t1}, gm	12.100	20.300	1.180	1.290	2.900
S_{t1}, ppm	4,630	7,760	452	492	1,110
Amount Withdrawn, gms	0.550	0.925	0.054	0.059	0.132
Amount Remaining, gms	11.550	19.375	1.126	0.231	2.768
Conc. after 8 days, C_{t2}, g/1	2.815	4.215	0.244	0.380	0.835
Leachates Existing, gms	14.750	22.300	1.280	2.000	4.380
Leachates Withdrawn, gms	0.716	1.053	0.061	0.096	0.209
Remaining, gms	14.034	20.247	1.219	1.904	4.171
Produced 1-8 days, gms	3.200	2.925	0.154	1.769	1.612
Produced 0-8, L_{t2}, gm	15.300	23.225	1.334	3.059	4.512
S_{t2}, ppm	5,850	8.900	510	1,175	1,730
Conc. after 40 days, C_{t3}, g/1	5.300	6.232	0.235	1.220	1.880
Leachate Existing, gms	26.500	31.200	1.180	6.100	9.400
Leachates Withdrawn, gm	1.325	1.550	0.059	0.305	0.471
Remaining, gms	25.175	29.640	1.121	5.795	8.929
Produced (8-40), gms	12.466	10.953	0.0	4.196	5.229
Produced (0-40), L_{t3}, gms	27.766	34.178	1.334	7.255	9.741
S_{t3}, ppm	10,600	13,100	510	2,780	3,730

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TABLE IV-18

COD/TDS RATIO DURING DECOMPOSITION FOR SERIES 1

Sample	COD/TDS Ratio		
	1 Day	8 Day	40 Day
BR 1-8	0.595	0.617	0.85
BR 2-4	0.973	0.935	1.180
CC 1-2	0.398	0.503	0.744
CC 2-3	1.700	1.070	1.090
TR	1.05	0.993	0.326
RH	0.837	1.075	0.907

TABLE IV-19

TOTAL LEACHABLE MATERIALS IN TONS/ACRE FT* FOR SERIES 1

Sample	COD	TDS	HRD	ALK	N
BR 1-8	4.27	5.28	1.12	1.50	0.205
BR 2-4	13.40	11.20	3.00	3.37	0.331
CC 1-2	2.87	3.87	2.19	1.31	0.015
CC 2-3	17.00	15.00	5.10	4.00	0.561
TR	4.02	10.16	2.68	2.60	0.069
RH	8.70	9.47	2.47	1.22	0.248

* Assuming refuse unit weight of 500 lbs/cubic yard.

TABLE IV-20

AMOUNT OF LEACHED MATERIAL
SERIES 2

Sample: 1-8
Sample wt. W_o: 1,394 gms
Water added for immersion: V_o = 1,700 mls

	COD	TDS	N	HRD	ALK
Conc. after 1 day, C_1 gm/1	2.060	3.056	0.187	0.230	0.525
Amount of Leachate, gm/ton	2,510	3,740	228	281	640
Conc. after 8 days, C_2 gm/1	2.615	3.085	0.187	0.310	0.719
Total amount of Leachate, gm/ton	3,560	4,340	262	419	970
Conc. after 40 days, gm/1	4.440	5.200	0.163	0.920	1.450
Total amount of Leachate, gm/ton	6,260	7,470	268	1,220	1,990

TABLE IV-21

LEACHABLE CHLORIDES, SULFATES, AND NITRATES FROM SERIES 1 AND 2*

Sample	Cl tons/acre ft		SO_4 tons/acre ft		NO_3 tons/acre ft	
	Series 1	Series 2	Series 1	Series 2	Series 1	Series 2
BR 1-8	0.603	0.252	0.0085	0	0.002	0.00074
BR 2-4	0.843	0.373	0	0	0.003	0.00255
CC 1-2	0.368	0.164	0.00131	0.00393	0.00066	0.00057
CC 2-3	0.675	0.356	0.87	0.434	0.0024	0.00246
TR	0.565	0.248	0.333	0.0297	0.0032	0.0114
RH	0.408	0.235	0.637	0.015	0.0016	0.00132

* Approximate values since these analyses were carried out only at the end of the experimental period.

TABLE IV-22

AMOUNT OF LEACHED MATERIAL
SERIES 3

Sample: BR 1-8
V_o: 1,800
W_o: 1,202 gms

	COD	TDS	N	HRD	ALK
Volume drained after 1 day, mls	1,290	1,290	1,290	1,290	1,290
Concentration, g/1	2.590	2.992	0.205	0.212	0.570
Amount withdrawn, gm	3.340	3.860	0.265	0.273	0.735
Vol drained after 8 days, mls	1,175	1,175	1,175	1,175	1,175
Concentration, g/1	2.110	1.980	0.135	0.230	0.590
Amount withdrawn, gm	2.480	2.330	0.159	0.270	0.694
Vol drained after 20 days, mls	1,120	1,120	1,120	1,120	1,120
Concentration, gm/1	1.790	1.805	0.091	0.370	0.718
Amount withdrawn, gms	2.000	2.020	0.102	0.414	0.205
Volume drained after 40 days	1,100	1,100	1,100	1,100	1,100
Concentration, gm/1	2.650	3.868	0.036	1.050	1.040
Amount withdrawn, gms	2.920	4.260	0.040	1.155	1.144

TABLE IV-23

VARIATION OF LEACHABLE TDS WITH TIME OBTAINED FROM SERIES 1 (Fig. IV-3)

Sample	ppm TDS of Refuse Material			
	1 Day	8 Days	23 Days	40 Days
BR 1-8	7,760	8,900	10,700	13,100
BR 2-4	14,700	19,000	23,000	27,800
CC 1-2	3,980	3,980	6,500	9,600
CC 2-3	19,000	35,900	36,500	37,180
TR	3,670	10,030	17,000	25,150
RH	5,030	15,250	19,000	23,500

TABLE IV-24

EXPECTED TDS LEACHATES BY LANDFILL WATERING

(Based on Data from Series 3)

	BR 1-8	BR 2-4	CC 1-2	CC 2-3
After first inundation:				
Leached TDS tons/acre ft	1.306	2.59	0.103	6.85
Inundation, 8 days later:				
Leached TDS tons/acre ft	0.781	1.53	0.112	2.98
Inundation, 23 days later:				
Leached TDS tons/acre ft	0.675	1.64	0.114	1.82
Inundation, 40 days later:				
Leached TDS tons/acre ft	1.426	2.13	0.28	1.67

APPENDIX E

GAS ANALYSIS DATA SHEETS

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 1

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
1	7/26/67	80-90	Clear-Hot	6.2	15.6	78.2	0.1	
	10/24/67	75-85	Clear-Warm	6.9	15.4	78.0	0.1	
	6/19/68	80-90	Hot-Clear	-	-	-	-	
	9/27/68	-	Warm	-	-	-	-	
	5/28/69	85	Clear	3.1	16.0	82.1	0	
2	7/26/67			17.8	4.0	78.2	Trace	
	10/24/67			17.1	2.9	80.0	0.3	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			13.5	6.8	82.1	0	
3	7/26/67			36.3	0.9	33.2	29.6	
	10/24/67			33.0	0.9	35.5	32.3	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			Trace	20.4	79.4	0.5	
4	7/26/67			43.5	0.4	8.0	46.5	In Manhole
	10/24/67			35.5	0.5	17.7	45.8	
	6/19/68			48.5	0.5	7.5	44.1	
	9/27/68			-	-	-	-	
	5/28/69			42.5	2.3	12.7	46.5	
5	7/26/67			39.7	2.2	11.9	43.8	In Manhole
	10/24/67			38.6	1.4	8.1	51.5	
	6/19/68			47.8	1.5	8.3	42.0	
	9/27/68			-	-	-	-	
	5/28/69			29.1	7.9	31.6	30.0	
6	7/26/67			42.0	1.8	9.3	45.3	In Manhole
	10/24/67			40.5	0.5	6.4	54.0	
	6/19/68			48.9	0.6	3.4	44.5	
	9/27/68			-	-	-	-	
	5/28/69			32.3	6.9	26.7	37.7	
7	7/26/67			36.7	2.8	24.4	35.0	
	10/24/67			38.4	0.5	17.0	43.1	
	6/19/68			44.8	0.6	16.0	35.5	
	9/27/68			-	-	-	-	
	5/28/69			43.2	1.1	13.1	42.3	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 1

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
8	7/26/67			43.0	0.5	7.1	46.5	
	10/24/67			39.4	0.5	10.7	46.6	
	6/19/68			47.1	0.3	5.5	43.5	
	9/27/68			-	-	-	-	
	5/28/69			42.2	2.0	12.6	44.1	
9	7/26/67			38.2	0.8	25.0	34.0	
	10/24/67			42.3	0.4	3.8	52.0	
	6/19/68			46.8	0.3	4.1	43.5	
	9/27/68			-	-	-	-	
	5/28/69			41.8	1.2	13.7	45.7	
10	7/26/67			46.2	0.3	1.7	49.3	In Manhole
	10/24/67			40.5	0.5	6.6	52.0	
	6/19/68			49.2	0.3	2.0	45.4	
	9/27/68			40.9	0.7	8.0	49.8	
	5/28/69			41.6	2.5	18.9	41.7	
11	7/26/67			45.3	0.5	2.2	48.8	In Manhole
	10/24/67			41.4	0.6	2.8	53.0	
	6/19/68			48.2	0.5	2.5	45.0	
	9/27/68			43.6	0.1	4.9	50.9	
	5/28/69			45.1	0.9	9.6	46.5	
12	7/26/67			28.2	8.9	33.8	28.7	In Manhole
	10/24/67			42.5	0.8	5.5	54.0	
	6/19/68			49.2	0.2	1.6	45.8	
	9/27/68			37.5	2.7	17.2	42.9	
	5/28/69			44.5	1.4	8.3	48.8	
13	7/26/67			43.0	0.5	7.2	45.7	
	10/24/67			42.3	0.2	3.6	51.1	
	6/19/68			47.8	0.4	4.0	44.5	
	9/27/68			33.8	2.4	23.4	37.7	
	5/28/69			34.4	1.8	42.4	22.8	
14	7/26/67			42.3	0.5	11.3	42.5	
	10/24/67			35.3	1.6	21.2	39.4	
	6/19/68			47.5	0.4	5.6	42.6	
	9/27/68			45.3	0	11.6	47.5	
	5/28/69			34.3	1.6	42.8	19.6	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 1

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
15	7/26/67			45.3	0.5	6.5	44.8	
	10/24/67			40.5	0.2	3.4	52.0	
	6/19/68			43.5	2.5	14.1	35.8	
	9/27/68			-	-	-	-	
	5/28/69			12.1	12.2	69.7	5.9	
16	7/26/67			38.6	0.7	25.2	32.6	
	10/24/67			34.2	0.9	37.3	31.9	
	6/19/68			46.3	0.6	6.9	42.6	
	9/27/68			-	-	-	-	
	5/28/69			21.4	3.1	77.0	0.8	
17	7/26/67			26.7	4.3	44.0	20.9	
	10/24/67			26.6	1.3	59.0	16.6	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			9.8	13.1	78.6	0.2	
18	7/26/67			20.7	0.7	63.5	11.8	
	10/24/67			17.9	1.3	68.8	9.2	
	6/19/68			33.3	0.8	38.0	24.3	
	9/27/68			-	-	-	-	
	5/28/69			27.5	2.4	43.9	28.5	
19	7/26/67			43.7	0.4	3.4	47.4	
	10/24/67			44.2	0.5	2.9	52.2	
	6/19/68			47.8	0.4	2.4	45.0	
	9/27/68			46.0	0.1	9.2	46.1	
	5/28/69			18.9	10.6	58.4	13.9	
20	7/26/67			Flooded				
	10/24/67			-	-	-	-	
	6/19/68			-	-	-	-	
	9/27/68							
	5/28/69			Trace	22.2	81.0	0	
21	7/26/67			10.7	13.2	69.8	2.0	
	10/24/67			-	-	-	-	
	6/19/68			10.6	13.6	64.0	7.1	
	9/27/68			-	-	-	-	
	5/28/69			8.2	12.8	82.3	0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 1

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
22	7/26/67			41.2	1.0	16.2	37.6	
	10/24/67			-	-	-	-	
	6/19/68			47.8	0.8	2.9	45.8	
	9/27/68			39.2	1.0	18.0	42.4	
	5/28/69			35.0	3.2	29.0	34.4	
23	7/26/67			43.4	0.5	5.5	45.7	
	10/24/67			44.5	0.2	1.3	54.9	
	6/19/68			48.5	0.3	2.0	47.2	
	9/27/68			46.3	0	4.1	49.7	
	5/28/69			8.9	17.2	68.6	7.6	
24	7/26/67			39.7	2.1	25.8	27.6	
	10/24/67			39.3	1.1	16.0	47.7	
	6/19/68			46.3	0.6	13.5	37.7	
	9/27/68			42.9	0.05	12.9	44.9	
	5/28/69			35.5	3.1	33.1	31.2	
25	7/26/67			3.3	19.4	72.4	Trace	
	10/24/67			0.7	21.9	77.2	Trace	
	6/19/68			2.0	19.9	74.8	Trace	
	9/27/68			-	-	-	-	
	5/28/69			0.6	21.9	80.4	Trace	
26	7/26/67			7.5	15.3	75.5	Nil	
	10/24/67			1.1	21.9	75.0	0	
	6/19/68			3.8	18.9	76.0	Nil	
	9/27/68			-	-	-	-	
	5/28/69			0	20.7	79.4	0	
27	7/26/67			43.7	0.8	14.9	40.2	
	10/24/67			38.5	0.6	16.0	43.6	
	6/19/68			38.6	2.8	29.9	28.3	
	9/27/68			34.6	1.3	23.9	39.5	
28	7/26/67			7.0	17.2	73.5	0.9	
	10/24/67			8.3	15.6	72.6	2.8	
	6/19/68			4.6	18.6	74.0	Trace	
	9/27/68			2.4	19.6	78.7	Trace	
29	7/26/67			42.3	0.4	10.2	43.8	
	10/24/67			40.4	0.7	6.5	49.5	
	6/19/68			43.5	0.5	10.8	43.1	
	9/27/68			Trace	20.7	79.2	0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 1

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
30	7/26/67			4.9	18.3	75.8	Trace	
	10/24/67			2.9	24.0	74.0	Trace	
	6/19/68			5.6	17.6	74.8	Trace	
	9/27/68			39.1	0.7	11.6	49.5	
31	7/26/67			29.1	1.0	41.0	25.3	
	10/24/67			28.5	1.2	45.0	24.2	
	6/19/68			27.9	4.4	43.8	21.3	
	9/27/68			-	-	-	-	
	5/28/69			15.9	9.6	59.9	13.0	
32	7/26/67			38.6	0.3	19.2	38.7	
	10/24/67			37.9	0.6	15.4	44.0	
	6/19/68			41.9	0.6	14.3	40.9	
	9/27/68			-	-	-	-	
	5/28/69			17.3	10.2	61.0	13.0	
33	7/26/67			39.2	0.3	17.5	39.0	
	10/24/67			36.3	0.8	24.0	37.6	
34	7/26/67			46.2	0.1	1.1	51.1	In Manhole
	10/24/67			-	-	-	-	
	6/19/68			48.5	0.3	2.8	46.6	
	9/27/68			35.6	0.8	9.6	54.5	
	5/28/69			32.3	3.9	32.3	30.9	
35	7/26/67			45.3	0.5	2.6	49.8	
	10/24/67			-	-	-	-	In Manhole
	6/19/68			47.5	0.3	2.2	46.6	
	9/27/68			38.7	0.2	5.4	55.1	
	5/28/69			39.2	1.6	21.2	39.1	
36	7/26/67			46.2	0.6	2.7	49.8	In Manhole
	10/24/67			-	-	-	-	
	6/19/68			48.2	0.3	2.0	47.2	
	9/27/68			43.5	Trace	3.4	53.4	
	5/28/69			1.7	21.1	77.9	2.2	
37	7/26/67			42.3	0.4	2.3	49.3	
38	7/26/67			4.1	18.0	74.0	Trace	
	10/24/67			3.3	18.5	79.0	Trace	
	6/19/68			-	-	-	-	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 1

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
38	9/27/68			-	-	-	-	
	5/28/69			4.6	16.9	80.2	0	
39	7/26/67			10.3	12.3	73.5	0.1	
	10/24/67			8.7	12.7	75.0	0.8	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			17.2	7.4	77.4	0.5	
40	7/26/67			13.3	10.5	71.3	1.0	
	10/24/67			16.2	7.1	73.0	Trace	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			28.5	3.9	53.2	16.8	
41	7/26/67			5.2	17.5	71.3	1.4	
	10/24/67			11.1	11.3	74.0	Trace	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			37.7	1.9	29.9	31.5	
42	7/26/67			3.0	19.1	73.5	Trace	
	10/24/67			2.9	20.9	77.0	0	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			2.9	19.3	80.7	0	
43	7/26/67			26.7	3.9	53.5	12.8	
44	7/26/67			14.4	12.0	72.6	Trace	
	10/24/67			-	-	-	-	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			1.5	20.5	81.1	0	
45	7/26/67			9.7	13.9	77.0	Trace	
	10/24/67			21.9	4.4	71.0	2.3	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			27.7	1.9	62.7	8.9	
46	7/26/67			29.4	4.2	51.8	14.2	
	10/24/67			24.2	4.1	65.0	9.3	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 1

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
46	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			34.6	2.4	20.3	37.9	
47	7/26/67			30.0	1.4	56.2	12.2	
	10/24/67			23.5	1.8	66.0	7.9	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			3.9	19.6	74.4	4.7	
48	7/26/67			25.8	1.3	69.5	3.7	
	10/24/67			23.5	1.3	68.0	6.2	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			32.1	4.9	38.1	25.6	
49	7/26/67			9.2	14.2	75.8	Trace	
	10/24/67			9.5	14.7	79.0	Trace	
	6/19/68			-	-	-	-	
	9/27/68			-	-	-	-	
	5/28/69			22.2	4.4	76.1	1.1	
50	7/26/67			32.6	1.0	50.2	16.0	
51	7/26/67			31.1	1.3	53.5	14.4	
52	7/26/67			26.4	3.3	61.8	8.6	
	10/24/67			22.8	2.9	72.0	4.1	
	6/19/68			28.5	1.2	62.9	6.2	
	9/27/68			-	-	-	-	
	5/28/69			24.2	4.9	60.4	5.8	
53	7/26/67			25.3	2.1	67.7	4.5	
	10/24/67			15.7	6.9	78.0	0.2	
	6/19/68			33.0	0.9	46.0	16.9	
	9/27/68			-	-	-	-	
	5/28/69			35.5	1.8	38.1	25.4	
54	7/26/67			33.3	1.6	39.8	23.7	
	10/24/67			30.2	2.9	45.0	22.0	
	6/19/68			37.0	0.7	34.7	24.4	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 1

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
55	7/26/67			34.8	1.0	44.3	20.5	
	10/24/67			32.9	0.9	45.5	20.4	
	6/19/68			41.2	0.7	28.9	27.7	
	9/27/68			-	-	-	-	
	5/28/69			42.6	1.4	13.2	43.4	
56	7/26/67			40.4	0.6	19.0	40.2	
	10/24/67			36.6	0.8	31.9	31.0	
	6/19/68			41.2	0.6	26.0	29.5	
	9/27/68			-	-	-	-	
	5/28/69			41.5	1.5	21.2	36.9	
57	7/26/67			42.3	0.5	11.4	43.8	
	10/24/67			38.8	1.6	18.5	41.0	
	6/19/68			44.2	0.5	12.0	39.5	
58	7/26/67			44.9	0.3	1.2	49.8	
	10/24/67			47.6	0.3	1.6	51.2	
	6/19/68			46.8	0.5	2.1	45.8	
59	7/26/67			40.7	0.7	20.4	37.5	
	10/24/67			42.4	0.7	15.5	44.0	
	6/19/68			20.7	10.1	50.1	15.9	
60	7/26/67			34.5	0.9	42.5	20.7	
	10/24/67			37.3	0.9	26.7	35.0	
	6/19/68			35.6	0.8	39.5	20.3	
61	7/26/67			36.0	0.8	31.7	29.4	
	10/24/67			32.5	5.5	32.5	33.0	
	6/19/68			37.0	0.7	36.0	23.6	
62	7/26/67			43.0	0.3	4.7	47.8	
	10/24/67			35.8	7.0	19.0	42.5	
	6/19/68			Nil	20.7	76.5	Nil	
63	7/26/67			43.1	0.8	11.6	44.3	
	10/24/67			44.0	0.3	9.1	48.5	
	6/19/68			44.1	0.4	18.2	35.8	
64	7/26/67			47.6	0.3	1.3	49.8	In Deep Well
	10/24/67			47.6	0.4	1.8	53.0	
	6/19/68			47.8	0.2	0.9	48.8	
	9/27/68			43.6	0.1	4.2	51.9	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 1

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
65	7/26/67			47.2	0.3	1.3	50.5	In Deep Well
	10/24/67			48.4	0.2	0.8	53.0	
	6/19/68			48.9	0.2	1.2	47.2	
	9/27/68			44.3	Trace	4.2	51.7	
66	7/26/67			46.2	0.3	1.3	51.4	In Deep Well
	10/24/67			47.6	0.2	0.6	54.0	
	6/19/68			50.4	0.2	1.1	47.6	
	9/27/68			40.1	0.2	3.9	55.7	
67	7/26/67			43.8	1.4	5.7	48.4	In Deep Well
	10/24/67			47.6	0.2	0.7	54.0	
	6/19/68			48.5	0.2	1.0	48.5	
	9/27/68			45.4	0.1	3.8	55.4	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 2A

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
1	3/16/67	-	Clear-Hot	44.5	1.4	50.6	Trace	
	7/7/67	90	Clear	68.1	1.0	29.5	0.3	
	10/12/67	85	Clear-Warm	57.0	2.1	41.5	0.7	
	12/6/68	70	Clear	75.4	0	3.2	19.5	
	2/21/69	60	Cloudy	73.0	0.8	4.4	25.7	
	6/11/69	65	Cloudy	35.7	9.5	37.5	13.3	
	8/6/69	80	Clear	35.2	9.4	38.5	13.1	
	10/23/69	70	Overcast	52.3	2.8	8.5	36.4	
	12/3/69	80	Clear	52.1	2.5	7.9	35.7	
2	3/16/67			51.8	2.3	50.6	Trace	
	7/7/67			60.2	2.4	34.0	0.3	
	10/12/67			81.0	0.7	18.2	2.0	
	12/6/68			5.0	20.9	74.5	0.6	
	2/21/69			4.2	21.0	76.8	1.3	
	6/11/69			12.3	16.7	64.7	4.5	
	8/6/69			Trace	21.0	77.4	0	
	10/23/69			0	22.1	77.2	0	
	12/3/69			1.4	21.4	74.6	0.4	
3	3/16/67			Plugged				
	7/7/67			-	-	-	-	
	10/12/67			68.0	2.3	31.0	Trace	
	12/6/68			4.6	18.2	76.0	0	
	2/21/69			1.6	20.4	81.5	0	
	6/11/69			0	21.5	71.2	0	
	8/6/69			0	21.0	77.7	0	
	10/23/69			Trace	22.2	77.2	0	
	12/3/69			0	21.8	76.2	0	Water in Probe
4	3/16/67			Plugged				
	7/7/67			-	-	-	-	
	10/12/67			24.0	11.8	62.5	Trace	
	12/6/68			1.1	18.4	77.9	0	
	2/21/69			1.8	20.0	82.7	0	Possibly Plugged
	6/11/69			Trace	20.6	80.0	0	
	8/6/69			7.2	15.8	75.4	0	
	10/23/69			3.8	19.0	78.0	0	
	12/3/69			5.1	17.2	75.8	0	
5	3/16/67			32.5	7.7	62.3	Nil	
	7/7/67			53.1	1.7	43.2	Trace	
	10/12/67			65.0	3.6	32.5	0.0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 2A

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
5	12/6/68			Trace	20.5	77.1	0	
	2/21/69			Trace	22.8	81.0	0	Water in Probe
	6/11/69			0	21.0	79.6	0	
	8/6/69			0	21.0	78.4	0	
	10/23/69			0	21.4	74.6	0	
	12/3/69			Water in Probe				
6	3/16/67			29.8	3.2	69.5	Nil	
	7/7/67			37.8	2.5	57.0	Trace	
	10/12/67			48.4	3.1	48.5	0.4	
	12/6/68			1.8	19.9	74.9	0	
	2/21/69			0	23.1	81.2	0	Water in Probe
	6/11/69			0	21.3	79.6	0	
	8/6/69			0	21.0	78.3	0	
	10/23/69			0	23.8	77.6	0	
	12/3/69			Trace	22.3	75.4	0	
7	3/16/67			31.2	1.5	68.3	Nil	
	7/7/67			-	-	-	-	
	10/12/67			56.6	1.2	42.0	0.3	
	12/6/68			Trace	23.0	76.6	0	
	2/21/69			Trace	21.9	81.8	0	Water in Probe
	6/11/69			0	21.8	81.3	0	
	8/6/69			0	20.6	78.6	0	
	10/23/69			0	22.8	77.4	0	
	12/3/69			Water in Probe				
8	3/16/67			24.0	2.2	70.2	Nil	
	7/7/67			35.3	1.5	60.5	Trace	
	10/12/67			59.3	1.1	39.0	0.6	
	12/6/68			66.3	2.0	18.8	9.1	
	2/21/69			78.1	1.0	7.2	17.7	
	6/11/69			30.4	12.5	49.7	9.1	
	8/6/69			0.2	18.5	77.7	0	
	10/23/69			0	22.2	78.2	0	
	12/3/69			0	23.1	76.2	0	Water in Probe
9	3/16/67			24.7	1.6	71.5	Nil	
	7/7/67			36.1	1.5	59.4	Trace	
	10/12/67			-	-	-	-	
	12/6/68			77.2	0.4	7.7	10.6	
	2/21/69			76.6	0.8	16.8	9.0	
	6/11/69			2.3	19.8	77.2	0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 2A

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
9	8/6/69			0	20.2	76.9	0	
	10/23/69			0	23.6	77.4	0	
	12/3/69			Trace	21.8	75.4	0	Water in Probe
10	3/16/67			26.6	1.7	72.3	Nil	
	7/7/67			29.6	1.8	66.4	Trace	
	10/12/67			55.8	1.5	45.0	0.3	
	12/6/68			66.9	3.1	15.2	11.4	
	2/21/69			79.1	1.1	7.8	15.4	Water in Probe
	6/11/69			32.0	12.2	48.0	8.0	
	8/6/69			0	19.9	77.7	0	
	10/23/69			0	22.6	77.4	0	
	12/3/69			4.2	21.0	74.6	0	Water in Probe
11	3/16/67			26.7	1.5	69.5	Nil	
	7/7/67			31.4	1.7	63.5	Trace	
	10/12/67			37.9	2.1	56.5	Trace	
	12/6/68			Trace	20.8	77.0	0	
	2/21/69			Trace	22.6	80.5	0	
	6/11/69			Trace	21.8	80.4	0	
	8/6/69			0	20.4	78.0	0	
	10/23/69			0	23.5	77.4	0	
	12/3/69			0	21.8	77.0	0	Plugged
12	3/16/67			24.7	3.0	70.0	Nil	
	7/7/67			30.8	2.2	64.0	Trace	
	10/12/67			43.6	2.1	55.0	Trace	
	12/6/68			60.6	2.7	27.4	7.4	
	2/21/69			66.0	1.9	26.0	6.8	Possibly Plugged
	6/11/69			38.1	11.0	46.0	5.6	
	8/6/69			28.7	12.7	45.2	8.3	
	10/23/69			4.6	21.4	73.4	2.1	
	12/3/69			Plugged				
13	3/16/67			15.5	10.2	74.0	Nil	
	7/7/67			30.4	1.8	65.7	Trace	
	10/12/67			40.6	1.5	58.0	Trace	
	12/6/68			65.1	1.8	27.6	3.3	
	2/21/69			61.9	2.3	29.3	5.9	Possibly Plugged
	6/11/69			54.4	6.9	33.5	6.9	
	8/6/69			0	24.4	77.6	0	
	10/23/69			59.7	6.8	25.4	10.9	
	12/3/69			49.3	8.4	33.3	8.2	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 2A

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
14	3/16/67			9.0	16.8	72.4	Nil	
	7/7/67			42.3	2.9	53.0	Trace	
	10/12/67			52.8	2.0	46.6	Trace	
	12/6/68			62.4	3.4	27.7	4.6	
	2/21/69			30.5	13.3	54.8	3.2	
	6/11/69			70.5	3.1	19.6	8.8	
	8/6/69			24.1	14.2	52.7	4.8	
	10/23/69			66.7	4.8	18.5	10.5	
	12/3/69			63.7	5.0	19.8	10.6	
15	3/16/67			25.4	3.4	69.5	Nil	
	7/7/67			31.0	2.3	64.0	Trace	
	10/12/67			33.5	5.1	60.0	0.0	
	12/6/68			52.6	3.5	41.4	0.5	
	2/21/69			19.9	15.7	66.0	0	Possibly Plugged
	6/11/69			0.4	20.4	79.4	0	
	8/6/69			6.4	18.5	71.6	1.0	
	10/23/69			39.9	10.7	44.4	5.1	
	12/3/69			65.1	5.0	21.4	7.6	
16	3/16/67			36.7	1.9	59.0	Nil	
	7/7/67			-	-	-	-	
	10/12/67			58.3	1.1	41.7	0.0	
	12/6/68			Trace	20.0	76.9	0	
	2/21/69			Trace	22.2	82.3	0	
	6/11/69			0	20.9	79.7	0	
	8/6/69			0	20.8	77.9	0	
	10/23/69			0	22.2	77.4	0	
	12/3/69			Water in Probe				
17	3/16/67			13.1	14.2	69.0	Nil	
	7/7/67			-	-	-	-	
	10/12/67			46.2	3.7	49.5	0.0	
	12/6/68			40.0	7.3	48.0	0	
	2/21/69			40.6	8.6	52.7	0	
	6/11/69			0	21.5	80.5	0	
	8/6/69			0	21.5	78.4	0	
	10/23/69			0	23.1	77.8	0	
	12/3/69			0	21.8	76.2	0	
18	3/16/67			47.0	2.2	48.5	Nil	
	7/7/67			-	-	-	-	
	10/12/67			65.3	1.4	31.4	0.0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 2A

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
18	12/6/68			53.9	4.4	38.0	0.2	
	2/21/69			35.7	10.4	56.3	0	
	6/11/69			2.3	20.4	77.5	0	
	8/6/69			0	21.9	79.2	0	
	10/23/69			17.0	18.4	67.3	0	
	12/3/69			58.2	6.7	31.0	3.9	
19	3/16/67			29.8	6.2	61.6	Nil	
	7/7/67			-	-	-	-	
	10/12/67			60.5	1.5	37.0	Trace	
	12/6/68			Trace	20.6	76.3	0	
	2/21/69			Trace	22.6	81.6	0	
	6/11/69			0	21.5	80.4	0	
	8/6/69			0	22.4	80.0	0	
	10/23/69			0	23.1	77.4	0	
	12/3/69			Water in Probe				

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 3

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
1	7/14/67	80	Clear	19.8	1.2	75.3	2.8	
	1/24/68	75-80	Clear-Warm	22.3	1.3	68.5	6.9	
2	7/14/67			4.0	18.9	75.3	Nil	
	1/24/68			3.4	18.2	77.0	Trace	
3	7/14/67			3.9	18.9	74.8	Nil	
4	7/14/67			3.1	19.6	75.5	Trace	
5	7/14/67			2.5	19.8	74.0	Trace	
	1/24/68			2.5	18.5	77.8	Nil	
6	7/14/67			2.7	19.8	74.8	Nil	
7	7/14/67			2.4	20.0	74.0	Nil	
8	7/14/67			40.0	0.2	21.9	34.3	
	1/24/68			39.7	0.3	8.2	46.5	
9	7/14/67			38.2	0.3	18.0	39.0	
	1/24/68			36.1	0.6	20.7	39.0	
10	7/14/67			24.2	1.8	63.5	7.3	
	1/24/68			28.2	1.0	52.5	16.5	
11	7/14/67			27.5	1.1	54.6	14.0	
	1/24/68			30.5	0.8	43.9	21.8	
12	7/14/67			26.4	1.2	60.0	7.1	
	1/24/68			28.8	1.1	54.1	14.1	
13	7/14/67			23.5	1.4	70.4	1.3	
	1/24/68			26.0	1.2	65.0	7.5	
14	7/14/67			4.8	17.9	73.3	Nil	
	1/24/68			5.4	15.6	78.5	Trace	
15	7/14/67			19.2	3.3	73.3	0.6	
	1/24/68			14.8	6.3	79.9	Nil	
16	7/14/67			4.8	17.9	72.8	Nil	
	1/24/68			2.7	18.2	79.2	Nil	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 3

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
17	7/14/67			5.0	18.1	72.8	Nil	
	1/24/68			-	-	-	-	
18	7/14/67			7.7	15.6	72.8	Nil	
	1/24/68			2.0	19.6	77.4	Nil	
19	7/14/67			10.2	14.7	71.1	Nil	
	1/24/68			4.6	18.3	77.0	Nil	
20	7/14/67			19.8	3.8	71.6	0.8	
	1/24/68			12.2	11.6	76.6	Nil	
21	7/14/67			22.7	4.3	65.2	6.0	
	1/24/68			23.5	1.4	58.1	16.7	
22	7/14/67			-	-	-	-	
	1/24/68			26.1	1.2	55.5	16.1	
23	7/14/67			5.8	16.0	73.3	Nil	
	1/24/68			0.5	20.5	76.3	Trace	
24	7/14/67			0.3	20.8	78.2	Nil	
	1/24/68			0.6	20.5	75.7	Nil	
25	7/14/67			1.5	20.7	76.9	Nil	
	1/24/68			0.15	20.5	75.9	Nil	
26	7/14/67			2.5	20.8	76.9	Nil	
	1/24/68			2.5	18.6	75.7	Nil	
27	7/14/67			33.1	1.0	43.0	23.4	
	1/24/68			26.8	5.6	33.5	29.8	
28	7/14/67			27.5	1.2	46.9	23.0	
	1/24/68			9.6	14.3	62.8	9.1	
29	7/14/67			19.5	3.4	74.8	0.3	
30	7/14/67			9.4	15.2	73.3	Trace	
	1/24/68			14.0	8.0	72.4	3.8	
31	7/14/67			8.8	14.5	74.8	Trace	
32	7/14/67			16.7	7.5	73.3	0.4	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 3

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
33	7/14/67			23.2	1.9	72.5	0.7	
34	7/14/67			33.8	0.8	31.5	31.7	
35	7/14/67			31.8	0.9	47.5	17.0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 4

(Percent by Volume

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
2	7/6/67	85	Clear-Smoggy	33.2	2.0	53.3	14.0	
	2/21/68	65	Overcast	34.8	0.8	41.0	19.8	
202	7/6/67			23.6	4.5	73.3	Nil	
	2/21/68			30.4	1.2	53.5	12.5	
205	7/6/67			3.4	19.6	76.8	Nil	
	2/21/68			4.8	16.3	74.8	Nil	
3	7/6/67			6.6	17.5	74.5	0.3	
	2/21/68			5.8	17.0	73.4	Trace	
302	7/6/67			10.0	14.5	75.4	Nil	
	2/21/68			10.3	11.9	74.8	Trace	
304	7/6/67			31.0	1.6	60.0	8.3	
	2/21/68			31.7	1.8	50.7	14.0	
4	7/6/67			4.3	18.9	75.0	Nil	
	2/21/68			4.7	17.6	73.4	Trace	
402	7/6/67			45.6	0.3	6.4	46.5	
	2/21/68			44.5	1.3	6.8	41.7	
406	7/6/67			6.9	16.0	75.0	Trace	
	2/21/68			6.9	15.3	72.9	0.1	
5	7/6/67			13.8	10.6	73.8	Nil	
	2/21/68			27.4	1.2	57.4	7.6	
503	7/6/67			37.5	0.7	40.5	21.5	
	2/21/68			43.8	1.0	6.8	42.3	
504	7/6/67			46.7	0.2	3.0	48.2	
	2/21/68			44.5	0.3	2.3	45.9	
6	7/6/67			4.5	18.6	73.8	Trace	
	2/21/68			5.0	17.5	72.9	0.1	
602	7/6/67			5.5	17.8	73.3	Trace	
	2/21/68			15.9	4.4	74.8	0.1	
603	7/6/67			45.3	0.2	1.2	50.5	
	2/21/68			45.2	0.3	1.8	46.8	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 4

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
605	7/6/67			31.1	0.9	46.0	21.3	
	2/21/68			36.3	0.6	10.8	46.3	
7	7/6/67			4.2	18.6	73.3	0.3	
	2/21/68			3.9	18.3	72.9	0.2	
702	7/6/67			42.6	0.7	28.5	27.2	
	2/21/68			31.3	0.9	36.3	26.7	
703	7/6/67			22.5	3.4	72.4	Nil	
	2/21/68			5.1	17.5	70.4	2.1	
705	7/6/67			8.8	14.8	72.9	Nil	
	2/21/68			8.2	11.3	75.4	0.1	
8	7/6/67			19.7	6.2	66.8	7.2	
	2/21/68			7.8	11.5	77.0	2.8	
801	7/6/67			24.7	0.8	40.2	25.1	
	2/21/68			44.2	0.5	2.8	48.5	
803	7/6/67			38.6	0.5	20.0	39.3	
	2/21/68			43.4	0.6	10.5	42.7	
9	7/6/67			43.3	0.2	0.6	52.3	
	2/21/68			44.5	0.4	1.9	49.4	
901	7/6/67			32.7	4.7	31.9	28.6	
	2/21/68			46.3	0.4	2.5	46.3	
902	7/6/67			5.0	17.3	74.5	0.3	
	2/21/68			34.2	0.8	27.2	33.2	
10	7/6/67			22.7	6.4	56.7	11.7	
	2/21/68			40.7	0.3	4.0	49.4	
1001N	7/6/67			45.6	0.3	0.8	49.8	
	2/21/68			46.3	0.4	1.8	47.2	
1001S	7/6/67			Trace	20.2	73.8	Trace	
	2/21/68			47.2	0.6	2.3	46.3	
1002	7/6/67			12.5	10.3	74.5	0.7	
	2/21/68			21.7	3.6	56.1	15.2	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 4

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
1101	7/6/67			30.9	2.3	46.9	17.5	
	2/21/68			40.7	0.3	12.5	42.9	
1102	7/6/67			27.3	7.9	33.0	29.3	
	2/21/68			44.2	0.4	2.5	47.2	
1L	7/6/67			21.6	9.0	45.5	20.7	
	2/21/68			34.3	4.3	18.6	35.8	
2L	7/6/67			3.7	18.1	74.5	Trace	
	2/21/68			10.0	1.7	81.9	2.2	
3L	7/6/67			36.7	2.0	13.0	45.5	
4L	7/6/67			30.0	0.4	22.5	43.0	
	2/21/68			22.0	1.1	38.2	32.6	
FB1	7/6/67			44.2	0.9	7.7	43.0	
	2/21/68			-	-	-	-	
FB2	7/6/67			34.2	4.8	20.0	37.5	
	2/21/68			-	-	-	-	
FB3	7/6/67			32.6	4.2	32.5	27.4	
FB4	7/6/67			26.7	4.3	51.0	15.2	
FB5	7/6/67			36.8	4.0	16.8	40.2	
FB6	7/6/67			18.8	8.0	59.5	12.4	
FB7	7/6/67			27.2	6.5	46.0	19.7	
FB8	7/6/67			28.5	6.8	37.5	26.0	
FB9	7/6/67			26.3	6.2	48.5	17.0	
	2/21/68			31.1	0.8	32.7	29.8	
FB10	7/6/67			3.6	18.6	75.5	0.2	
	2/21/68			3.9	16.6	74.8	0.1	
FB11	7/6/67			4.1	17.2	77.0	Trace	
	2/21/68			6.1	13.1	75.9	Trace	

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GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 4

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
FB12	7/6/67			41.9	3.1	15.0	41.5	
	2/21/68			44.2	0.4	3.3	46.3	
FB13	7/6/67			46.0	0.2	1.6	50.5	
	2/21/68			43.5	0.4	1.8	46.7	

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GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 5

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
1A	7/14/67	80	Clear	9.0	14.2	75.3	Nil	
	1/24/68	75-80	Warm-Clear	5.2	13.7	79.7	Nil	
1B	7/14/67			9.8	13.7	74.8	Nil	
	1/24/68			8.0	13.6	76.0	Nil	
1C	7/14/67			4.8	18.1	75.5	Nil	
	1/24/68			3.0	17.7	79.9	Nil	
1D	7/14/67			2.5	20.0	75.5	Nil	
	1/24/68			0.2	21.2	79.2	Nil	
2D	7/14/67			2.5	20.0	75.5	Nil	
3E	7/14/67			2.4	20.3	75.5	Nil	
4E	7/14/67			3.0	19.8	75.5	Nil	
	1/24/68			1.1	20.8	78.6	Nil	
4F	7/14/67			4.5	19.4	75.5	Trace	
	1/24/68			1.7	20.0	78.5	Nil	
3F	7/14/67			2.9	19.8	75.5	Nil	
	1/24/68			0.8	21.1	78.0	Nil	
4G	7/14/67			12.0	11.3	75.3	Nil	
	1/24/68			11.9	10.4	77.4	Nil	
3G	7/14/67			3.6	18.9	75.3	Trace	
	1/24/68			1.8	19.9	78.5	Nil	
3H	7/14/67			10.8	11.8	74.8	Trace	
2H	7/14/67			3.5	18.7	75.3	Trace	
	1/24/68			1.1	20.5	79.4	Nil	
1J	7/14/67			8.5	14.2	74.8	Nil	
6	7/14/67			2.8	19.7	75.3	Nil	
	1/24/68			0.7	21.2	79.4	Nil	
7	7/14/67			5.7	15.5	75.5	Nil	
	1/24/68			5.6	12.7	83.0	Nil	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 5

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
8	7/14/67			8.3	13.8	75.3	Nil	
9C	7/14/67			21.2	4.2	63.5	7.3	
	1/24/68			22.2	1.2	66.5	9.0	
9B	7/14/67			34.8	0.7	24.7	35.8	
	1/24/68			34.2	1.3	26.8	34.6	
10B	7/14/67			33.9	1.2	32.5	29.3	
	1/24/68			30.0	0.9	45.7	22.0	
10C	7/14/67			22.5	1.9	73.8	0.3	
9A	7/14/67			37.5	1.2	21.8	38.4	
	1/24/68			35.7	0.5	21.2	39.4	
10A	7/14/67			36.7	1.0	22.5	38.1	
	1/24/68			32.2	1.4	32.5	31.2	
11	7/14/67			26.4	1.5	61.1	10.2	
12	7/14/67			15.5	8.3	75.5	1.2	
13A	7/14/67			20.2	5.3	56.2	18.8	
13B	7/14/67			12.5	14.0	60.8	11.5	
13C	7/14/67			11.8	14.3	62.2	10.2	
13D	7/14/67			12.7	14.2	61.9	10.0	
13E	7/14/67			32.4	3.8	31.9	31.8	
14	7/14/67			30.3	0.9	41.8	25.7	
15E	7/14/67			26.2	4.3	56.2	12.3	
17B	7/14/67			5.1	17.7	74.7	Trace	
17C	7/14/67			4.6	18.3	74.7	Nil	
17D	7/14/67			2.8	19.6	74.7	Nil	
17E	7/14/67			4.3	17.1	74.0	Nil	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 5

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
18	7/14/67			4.2	16.0	68.2	Trace	
19	7/14/67			4.3	17.9	71.8	1.0	
20	7/14/67			Trace	19.7	73.5	Nil	
21A	7/14/67			10.6	7.0	79.6	Nil	
	1/24/68			9.3	8.1	83.5	Nil	
21B	7/14/67			7.2	6.9	83.0	Nil	
	1/24/68			6.0	10.0	84.8	Nil	
21C	7/14/67			7.2	8.9	81.3	Nil	
	1/24/68			6.7	5.6	89.0	Nil	
21D	7/14/67			3.2	18.5	74.7	Nil	
	1/24/68			6.9	6.3	88.0	Nil	
22	7/14/67			4.5	17.7	74.7	Nil	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 5

(Percent by Volume)

Date Sample Taken: 27 August 1969

Temperature: 70°F Weather: Clear

Date Sample Analyzed: 29 August 1969

Trench Probe	CO_2	O_2	N_2	CH_4
9A	34.6	2.1	30.7	34.7
9B	31.6	1.5	37.4	30.6
32	14.8	8.5	53.0	18.6
33	4.4	16.9	79.7	0
34	25.4	4.2	52.4	17.7
35	5.2	15.7	79.6	0
36	11.5	10.2	78.8	0
37	1.1	19.0	78.9	0
38	4.0	16.9	78.8	0
39	11.1	8.7	77.0	0

Date Sample Taken: 8 October 1969

Temperature: 75°F Weather: Warm-Hazy

Date Sample Analyzed: 9 October 1969

Trench Probe	CO_2	O_2	N_2	CH_4
32	30.9	0.9	34.3	30.9
33	3.0	16.2	76.5	0
34	26.4	2.8	44.1	22.5
35	3.7	15.7	77.8	0
36*	Trace	19.0	77.6	0
37	1.5	17.7	76.7	0
38	6.8	11.8	76.8	0
39	5.1	13.9	76.3	0

* Water in Probe

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 6

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
1A	6/15/67	70	Clear & Warm	4.0	18.2	78.0	Nil	
	8/23/67	85	Clear & Hot	-	-	-	-	
	2/8/68	55	Cool-Cloudy	1.5	19.6	72.8	Trace	
	1/3/69	78	Clear	Trace	20.1	77.8	0	Rain of 1.65 in. in month preceding
	1/31/69	55	Clear	-	-	-	-	
1B	6/15/67			-	-	-	-	
	8/23/67			2.9	19.3	73.5	Nil	
	2/8/68			0.6	20.0	73.3	Trace	
	1/3/69			Trace	20.1	79.0	0	
	1/31/69			-	-	-	-	
1C	6/15/67			-	-	-	-	
	8/23/67			2.3	18.6	68.2	Trace	
	2/8/68			8.5	8.2	79.7	Trace	
	1/3/69			0.6	16.9	81.4	0	
2A	6/15/67			1.1	19.2	78.6	Nil	
	8/23/67			-	-	-	-	
	2/8/68			0.6	18.9	73.9	Trace	
	1/3/69			0	20.5	78.3	0	
	1/31/69			0	7.3	88.2	0	
2B	6/15/67			1.5	20.2	78.2	Nil	
	8/23/67			2.8	19.4	73.5	Trace	
	2/8/68			1.4	18.9	73.9	Trace	
	1/3/69			Trace	20.4	78.7	0	
	1/31/69			-	-	-	-	
2C	6/15/67			-	-	-	-	
	8/23/67			2.4	18.5	68.2	Trace	
	2/8/68			4.7	15.1	75.7	0.1	
	1/3/69			Trace	20.2	79.5	0	
3A	6/15/67			1.8	19.4	79.5	Nil	
	8/23/67			-	-	-	-	
	2/8/68			0.8	19.3	73.3	Trace	
	1/3/69			0	20.7	79.3	0	
	1/31/69			Trace	4.8	85.2	4.6	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 6

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
3B	6/15/67			2.3	19.2	78.0	Nil	
	8/23/67			2.4	20.0	73.5	Nil	
	2/8/68			1.0	19.7	75.4	Nil	
	1/3/69			Trace	19.7	79.0	0	
	1/31/69			-	-	-	-	
3C	6/15/67			-	-	-	-	
	8/23/67			3.2	17.8	65.8	1.4	
	2/8/68			42.3	0.7	3.6	47.6	
	1/3/69			-	-	-	-	
	1/31/69			-	-	-	-	
4A	6/15/67			1.2	20.4	78.2	Nil	
	8/23/67			-	-	-	-	
	2/8/68			-	-	-	-	
4B	6/15/67			-	-	-	-	
	8/23/67			5.0	16.0	70.7	1.8	
	2/8/68			29.5	0.6	16.1	47.2	
	1/3/69			5.9	8.2	83.4	0	
	1/31/69			-	-	-	-	
4C	6/15/67			-	-	-	-	
	8/23/67			21.4	10.0	38.2	27.2	
	2/8/68			40.7	0.9	4.0	48.4	
	1/3/69			39.7	0.7	3.1	55.8	
	1/31/69			41.0	0	0	55.3	
5A	6/15/67			0.6	16.6	81.9	Nil	
	8/23/67			-	-	-	-	
	2/8/68			28.5	3.4	25.9	37.0	
	1/3/69			31.8	1.4	21.9	45.8	
	1/31/69			-	-	-	-	
5B	6/15/67			-	-	-	-	
	8/23/67			38.9	0.5	5.9	55.0	
	2/8/68			40.5	0.8	4.1	49.8	
	1/3/69			39.1	0.8	4.0	57.9	
	1/31/69			32.9	0	Trace	62.9	
5C	6/15/67			-	-	-	-	
	8/23/67			32.8	4.0	18.0	42.5	
	2/8/68			26.1	7.5	28.4	32.7	
	1/3/69			40.5	0.4	1.9	58.2	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 6

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
6A	6/15/67			Trace	20.2	78.6	Nil	
	8/23/67			-	-	-	-	
	2/8/68			12.7	1.5	76.9	5.0	
	1/3/69			3.6	14.9	76.5	0.9	
6B	6/15/67			-	-	-	-	
	8/23/67			24.3	9.0	36.3	30.3	
	2/8/68			38.6	1.1	4.8	48.8	
	1/3/69			35.8	2.6	13.4	47.5	
	1/31/69			25.0	5.9	28.0	35.9	
6C	6/15/67			-	-	-	-	
	8/23/67			8.7	16.0	69.5	3.0	
	2/8/68			8.3	15.5	71.0	0.1	
7A	6/15/67			0.6	20.4	77.5	Nil	
	8/23/67			-	-	-	-	
	2/8/68			9.0	7.3	79.4	0.4	
	1/3/69			5.1	12.5	79.3	0	
	1/31/69			12.4	1.7	33.7	49.1	
7B	6/15/67			-	-	-	-	
	8/23/67			0.5	20.3	77.8	0.4	
	2/8/68			8.6	11.4	56.7	18.0	
	1/3/69			2.4	16.0	79.0	0	
	1/31/69			30.2	Trace	5.6	59.7	
7C	6/15/67			-	-	-	-	
	8/23/67			43.0	0.2	0.6	53.8	
	2/8/68			41.2	0.5	2.4	49.8	
	1/3/69			40.8	0.4	2.2	57.2	
	1/31/69			41.5	0	Trace	55.1	
8A	6/15/67			1.1	20.1	77.2	Nil	
	8/23/67			-	-	-	-	
	2/8/68			0.3	20.3	72.8	Nil	
	1/3/69			0	20.2	78.1	0	
	1/31/69			0	21.4	76.7	0	
8B	6/15/67			-	-	-	-	
	8/23/67			2.4	19.5	77.0	1.3	
	2/8/68			0.6	19.2	74.7	0.5	
	1/3/69			Trace	19.7	80.5	0	
	1/31/69			17.1	0.4	32.3	47.6	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 6

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
8C	6/15/67			-	-	-	-	
	8/23/67			26.1	8.3	33.5	30.7	
	2/8/68			39.3	0.5	16.8	39.3	
9A	6/15/67			0.1	20.7	77.0	Nil	
	8/23/67			-	-	-	-	
	2/8/68			Nil	20.7	75.3	Nil	
	1/3/69			0	20.4	78.2	0	
	1/31/69			Trace	15.1	83.5	0	
9B	6/15/67			3.6	16.6	79.5	0.2	
	8/23/67			3.0	19.5	77.0	Nil	
	2/8/68			10.3	10.4	74.7	0.4	
	1/3/69			Trace	19.3	79.8	0	
	1/31/69			19.5	4.5	29.6	43.7	
9C	6/15/67			-	-	-	-	
	8/23/67			28.3	0.8	68.2	2.2	
	2/8/68			36.2	0.6	27.2	32.7	
10A	6/15/67			0.2	20.8	77.5	Nil	
	8/23/67			-	-	-	-	
	2/8/68			Nil	20.2	73.3	Nil	
	1/3/69			0	20.3	78.8	0	
	1/31/69			0	21.9	79.0	0	
10B	6/15/67			40.0	0.5	23.4	38.0	
	8/23/67			16.5	7.6	75.3	0.6	
	2/8/68			38.6	0.3	2.3	51.1	
10C	6/15/67			-	-	-	-	
	8/23/67			9.0	14.8	75.8	Trace	
	2/8/68			11.3	13.6	71.0	1.0	
11A	6/15/67			0.9	18.9	79.0	Nil	
	8/23/67			-	-	-	-	
	2/8/68			11.0	5.2	69.8	9.3	
	1/3/69			Trace	18.4	78.9	0	
	1/31/69			Trace	12.2	83.7	0.7	
11B	6/15/67			-	-	-	-	
	8/23/67			29.6	6.2	29.5	33.7	
	2/8/68			41.2	0.2	1.1	52.8	
	1/3/69			26.7	2.3	35.8	34.1	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 6

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
11C	6/15/67			-	-	-	-	
	8/23/67			13.4	11.6	73.5	0.5	
	2/8/68			20.1	9.4	56.2	10.9	
12A	6/15/67			3.1	18.6	76.3	Nil	
	8/23/67			-	-	-	-	
	2/8/68			0.9	19.1	75.7	Nil	
	1/3/69			0.9	17.7	79.2	0	
12B	6/15/67			21.6	0.7	49.0	30.8	
	8/23/67			11.0	10.8	76.5	Trace	
	2/8/68			16.9	6.3	33.0	37.2	
	1/3/69			0	19.4	79.0	0	
13A	6/15/67			4.0	19.1	75.6	Nil	
	8/23/67			-	-	-	-	
	2/8/68			6.5	8.1	78.7	1.6	
	1/3/69			0.3	17.2	79.7	0	
13B	6/15/67			7.7	15.9	79.0	Nil	
	8/23/67			2.6	20.0	75.8	Nil	
	2/8/68			27.2	0.5	10.0	54.2	
13C	6/15/67			14.2	12.8	48.0	24.0	
	8/23/67			-	-	-	-	
	2/8/68			41.9	0.3	1.5	52.2	
14A	6/15/67			1.5	19.3	75.6	Nil	
	8/23/67			-	-	-	-	
	2/8/68			1.3	19.3	75.7	Nil	
14B	6/15/67			-	-	-	-	
	8/23/67			3.5	18.9	75.3	Nil	
	2/8/68			15.2	2.0	53.9	23.3	
	1/3/69			1.8	15.0	80.9	0	
14C	6/15/67			-	-	-	-	
	8/23/67			3.8	19.1	71.0	4.7	
15A	6/15/67			-	-	-	-	
	8/23/67			5.7	16.0	76.5	Trace	
	2/8/68			2.9	16.2	76.9	Nil	
	1/3/69			0.3	17.6	80.6	0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 6

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
15B	6/15/67			-	-	-	-	
	8/23/67			4.5	18.1	75.3	Nil	
	2/8/68			1.5	18.9	73.3	0.1	
	1/3/69			Trace	19.9	77.6	0	
	1/31/69			0.2	14.7	82.6	0	
15C	6/15/67			-	-	-	-	
	8/23/67			17.2	7.1	75.8	Trace	
	2/8/68			30.7	0.7	34.5	32.6	
	1/3/69			3.9	15.7	79.4	0	
16A	6/15/67			-	-	-	-	
	8/23/67			4.7	17.3	75.3	Nil	
	2/8/68			2.7	17.2	76.5	Nil	
	1/3/69			0.3	18.7	78.1	0	
	1/31/69			0.6	18.7	76.9	0	
16B	6/15/67			-	-	-	-	
	8/23/67			35.2	0.7	29.0	33.7	
	2/8/68			37.5	0.4	8.7	47.2	
	1/3/69			17.3	4.2	64.6	13.7	
16C	6/15/67			-	-	-	-	
	8/23/67			35.3	0.8	33.0	31.7	
	2/8/68			37.6	0.8	14.3	44.2	
	1/3/69			30.0	1.1	36.5	32.0	
	1/31/69			30.4	4.1	17.2	46.8	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 7

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
1	8/8/67	80-95	Clear-Hot	5.3	16.8	74.0	Nil	
	2/21/67			5.4	17.0	74.8	Nil	
2	8/8/67			28.5	1.2	55.0	12.4	
	2/21/67			38.6	0.9	16.3	41.0	
3	8/8/67			5.9	16.3	74.0	Nil	
	2/21/67			6.6	16.1	73.4	0.2	
4	8/8/67			39.3	1.0	36.3	23.4	
	2/21/67			44.9	0.5	7.2	43.8	
5	8/8/67			17.2	7.0	73.5	0.2	
	2/21/67			26.7	1.6	60.7	7.7	
6	8/8/67			2.8	19.5	73.5	Nil	
	2/21/67			4.1	17.6	75.4	Nil	
7	8/8/67			7.5	14.1	76.6	Nil	
8	8/8/67			2.5	20.2	75.3	Nil	
9	8/8/67			2.5	20.0	74.6	Nil	
	2/21/67			2.2	19.6	74.8	Nil	
10	8/8/67			2.7	19.8	74.6	Nil	
	2/21/67			3.0	19.4	74.8	Nil	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 8

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
1A	5/9/67	65	Warm-Cloudy	41.9	0.9	4.0	52.6	
	9/13/67	75	Warm-Cloudy	18.4	10.6	48.8	22.2	
	11/18/68	75	Smoggy-Warm	31.3	0	35.0	32.0	
	12/17/68	60	Clear	34.4	0.7	29.3	35.5	
	1/15/69	70	Clear	19.7	0.4	52.9	24.3	Rain of 1.74 in. on 1/13-14/69
	2/28/69	60	Cloudy	43.2	0.3	3.9	53.2	Rain totally 34.5 in. in two months preceding
	9/17/69	75	Clear	Destroyed				
	11/5/69	60	Cloudy					
1B	5/9/67			29.7	0.5	27.9	44.8	
	9/13/67			33.9	0.7	28.2	45.0	
	11/18/68			6.4	3.3	80.6	Trace	
	12/17/68			9.6	8.9	77.5	0	
	1/15/69			10.7	7.7	79.8	0	
	2/28/69			-	-	-	-	
	9/17/69			-	-	-	-	
	11/5/69			Destroyed				
1C	5/9/67			34.8	0.7	19.3	47.5	
	9/13/67			36.0	0.4	30.7	42.7	
	11/18/68			4.2	6.7	80.8	0	
	12/17/68			8.7	10.3	78.5	0	
	1/15/69			4.3	15.5	78.4	0	
	2/28/69			-	-	-	-	
	9/17/69			-	-	-	-	
	11/5/69			Destroyed				
2A	5/9/67			4.3	19.9	78.5	Nil	
	9/13/67			-	-	-	-	
	11/18/68			0.9	16.2	75.7	0	
	12/17/68			1.0	19.8	76.9	0	
	1/15/69			1.0	20.9	78.4	0	
	2/28/69			-	-	-	-	
	9/17/69			Trace	20.6	79.0	0	
	11/5/69			Destroyed				
2B	5/9/67			38.8	0.3	1.1	55.4	
	9/13/67			36.7	0.4	17.7	43.9	
	11/18/68			31.6	0	24.6	44.0	

GAS ANALYSIS DATA
PROJECT SUMMARY
Site 8

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
2B	12/17/68			32.8	0.5	23.8	40.9	
	1/15/69			17.9	10.4	46.3	23.9	
	2/28/69			-	-	-	-	
	9/17/69			Destroyed				
	11/15/69			16.6	13.6	52.0	20.4	
2C	5/9/67			43.7	0.2	0.9	56.8	
	9/13/67			36.0	0.8	26.4	42.7	
	11/18/68			24.7	0	50.0	21.6	
	12/17/68			27.2	1.4	44.0	23.8	
	1/15/69			-	-	-	-	
	2/28/69			-	-	-	-	
	9/17/69			22.4	5.4	46.3	25.0	
	11/5/69			28.8	3.8	38.0	29.9	
2D	5/9/67			41.4	0.4	3.6	54.2	
	9/13/67			31.3	1.1	38.3	29.3	
	11/18/68			5.3	7.9	66.0	12.7	
	12/17/68			30.6	0.5	29.8	37.4	
	1/15/69			19.0	6.3	47.9	25.0	
	2/28/69			-	-	-	-	
	9/17/69			31.1	0.9	30.5	35.7	
	11/5/69			Destroyed				
3A	5/9/67			44.5	0.5	2.5	51.2	
	9/13/67			37.8	0.7	17.6	43.9	
	11/18/68			25.7	0	45.2	30.4	
	12/17/68			30.2	1.7	31.4	34.5	
	1/15/69			27.4	2.2	39.8	27.9	
	2/28/69			-	-	-	-	
	9/17/69			29.4	3.1	29.9	40.3	
	11/5/69			22.9	7.7	46.8	26.8	
3B	5/9/67			42.3	0.3	6.3	50.5	
	9/13/67			27.7	1.3	57.5	13.5	
	11/18/68			4.0	0	81.7	0	
	12/17/68			5.4	14.5	77.0	0	
	1/15/69			5.7	14.5	77.3	0	
	2/28/69			-	-	-	-	
	9/17/69			3.0	17.3	80.0	0	
	11/5/69			3.8	18.8	79.0	0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 8

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
4A	5/9/67			39.3	0.4	14.8	45.3	
	9/13/67			25.5	1.1	58.9	14.5	
	11/18/68			23.7	0	58.5	17.2	
	12/17/68			22.5	0.4	60.6	11.6	
	1/15/69			24.7	0.7	59.7	14.6	
	2/28/69			-	-	-	-	
	9/17/69			Destroyed				
	11/5/69			Destroyed				
5	5/9/67			3.2	20.1	76.8	Nil	
	9/13/67			1.3	18.7	75.6	Trace	
	11/18/68			Trace	20.6	82.3	0	
	12/17/68			0.2	19.4	75.7	0	
	1/15/69			-	-	-	-	
	2/28/69			-	-	-	-	
	9/17/69			-	-	-	-	
	11/5/69			Destroyed				
6	5/9/67			15.4	4.7	66.9	10.6	
	9/13/67			5.5	17.5	80.0	0.0	
	11/18/68			0.6	18.5	82.3	0	
	12/17/68			1.1	20.4	74.0	0	
	1/15/69			0.6	20.4	77.0	0	
	2/28/69			2.5	14.7	84.8	0	
	9/17/69			1.6	18.1	79.5	0	
	11/5/69			1.4	20.9	75.0	0	
6A	5/9/67			19.5	1.2	56.4	22.5	
	9/13/67			9.5	13.0	78.0	Trace	
	11/18/68			1.1	15.4	81.9	0	
	12/17/68			2.8	19.5	74.2	0	
	1/15/69			1.6	19.9	78.0	0	
	2/28/69			3.2	12.9	85.5	0	
	9/17/69			5.3	15.2	79.7	0	
	11/5/69			4.9	19.2	75.8	0	
7A	5/9/67			39.5	0.4	9.9	49.7	
	9/13/67			34.5	0.7	19.0	47.5	
	11/18/68			26.4	0	57.7	17.6	
	12/17/68			14.4	8.5	68.4	6.3	
	1/15/69			18.1	2.7	72.0	5.0	
	2/28/69			25.7	0.7	47.1	25.5	
	9/17/69			35.8	2.2	21.7	42.8	
	11/5/69			25.3	4.3	50.0	20.4	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 8

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
7B	5/9/67			43.0	0.3	2.4	56.0	
	9/13/67			29.0	4.5	21.9	46.0	
	11/18/68			10.0	3.0	60.3	18.2	
7C	9/17/69			34.8	1.1	15.5	44.4	
	11/5/69			27.4	6.4	34.3	35.8	
8	5/9/67			42.3	0.5	3.7	55.8	
	9/13/67			38.0	0.6	6.4	54.5	
	11/18/68			22.7	0	57.7	19.1	
	12/17/68			5.2	17.6	74.7	0	
	1/15/69			-	-	-	-	
	2/28/69			Flooded				
	9/17/69			18.0	5.6	57.1	15.7	
	11/5/69			18.7	7.7	62.7	10.8	
8A	5/9/67			41.5	0.2	2.2	57.4	
	9/13/67			37.0	0.7	5.1	56.6	
	11/18/68			7.2	6.9	70.6	13.2	
	12/17/68			18.9	10.5	54.5	14.0	
8B	9/17/69			11.1	14.2	63.5	9.3	
	11/5/69			15.3	12.4	63.7	8.6	
9A	5/9/67			47.2	0.2	9.6	45.8	
	9/13/67			37.0	0.7	19.0	44.5	
	11/18/68			21.7	0	61.9	14.4	
	12/17/68			21.8	10.2	66.4	6.8	
	1/15/69			22.9	0.9	66.5	10.3	
	2/28/69			21.6	3.6	45.0	25.6	
	9/17/69			Destroyed				
9B	5/9/67			41.2	0.2	3.7	55.0	
	9/13/67			37.9	0.5	11.6	50.0	
9C	9/17/69			31.1	2.6	37.6	31.0	
	11/5/69			20.1	6.4	66.1	7.3	
10	5/9/67			35.2	1.0	34.8	30.3	
	9/13/67			-	-	-	-	
	11/18/68			24.1	0	44.9	29.7	
	12/17/68			17.3	7.6	57.0	14.3	
	1/15/69			24.9	1.1	50.0	23.3	
	2/28/69			25.0	0.5	28.1	42.1	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 8

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
10	9/17/69			20.5	1.9	69.2	8.4	
	11/5/69			7.6	15.4	75.8	0	
10A	5/9/67			43.5	0.1	1.2	54.2	
	9/13/67			39.1	0.3	7.6	52.0	
	11/18/68			22.4	0	32.3	37.9	
	12/17/68			20.4	8.6	42.0	26.2	
	1/15/69			28.8	3.9	34.7	33.2	
	2/28/69			29.1	2.5	26.2	37.5	
	9/17/69			18.4	7.4	57.4	16.8	
	11/5/69			21.9	3.0	62.1	13.0	
11A	5/9/67			36.5	0.3	12.4	48.7	
	9/13/67			26.2	12.6	49.7	12.0	
	11/18/68			2.4	6.6	80.9	2.3	
	12/17/68			1.2	20.1	77.0	0	
	1/15/69			2.6	15.2	81.3	0	
	2/28/69			5.9	8.7	84.3	0.7	
	9/17/69			Destroyed				
	11/5/69			Destroyed				
12	5/9/67			3.7	19.0	75.2	Trace	
	9/13/67			3.0	21.2	76.8	Trace	
13	5/9/67			23.9	2.5	69.0	2.4	
	9/13/67			18.8	5.3	74.0	0.2	
	11/18/68			1.4	12.0	80.0	0	
	12/17/68			1.4	20.4	76.5	0	
	1/15/69			4.7	15.8	79.0	0	
	2/28/69			Flooded				
	9/17/69			0.3	19.8	81.4	0	
	11/5/69			6.9	18.4	76.2	0	
13A	5/9/67			35.5	0.5	15.2	45.0	
	9/13/67			31.0	1.2	37.5	31.4	
	11/18/68			0.8	15.8	79.6	0	
	12/17/68			4.7	17.0	76.0	0	
	1/15/69			7.8	14.7	76.6	0	
	2/28/69			Flooded				
	9/17/69			Plugged				
	11/5/69			18.8	8.5	71.8	1.4	
13B	5/9/67			24.1	5.8	41.0	27.3	
	9/13/67			15.9	7.4	75.5	Trace	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 8

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
13B	11/18/68			0	20.8	81.2	0	
	12/17/68			1.8	19.3	75.7	0	
13C	9/17/69			2.7	16.7	80.4	0	
	11/5/69			2.3	19.7	76.0	0	
14	5/9/67			28.8	5.7	24.7	38.5	
	9/13/67			22.6	5.0	32.2	40.5	
14A	9/17/69			9.5	15.0	59.7	14.6	
	11/5/69			24.3	5.1	50.8	20.9	
15A	5/9/67			36.7	0.2	5.2	54.5	
	9/13/67			33.4	0.3	13.3	52.5	
	11/18/68			29.6	0	25.8	42.9	
	12/17/68			27.0	7.0	29.9	35.5	
	1/15/69			29.4	1.7	31.8	39.3	
	2/28/69			36.9	Trace	12.0	46.8	
	9/17/69			Trace	21.7	80.7	0	
	11/5/69			23.6	3.0	56.9	16.4	
16A	5/9/67			23.2	1.0	69.8	4.3	
	9/13/67			7.9	14.7	76.0	0.0	
	11/18/68			-	-	-	-	
	12/17/68			0.1	20.0	76.5	0	
	1/15/69			0.5	20.4	78.7	0	
	2/28/69			3.2	13.3	84.0	0	
	9/17/69			2.0	19.0	79.0	0	
	11/5/69			2.8	20.9	76.6	0	
17	5/9/67			8.2	13.7	75.0	Trace	
	9/13/67			5.9	17.5	75.0	0.0	
	11/18/68			-	-	-	-	
	12/17/68			1.2	20.5	76.4	0	
	1/15/69			Trace	21.8	79.1	0	
18B	5/9/67			7.0	9.9	80.5	Trace	
	9/13/67			6.7	17.7	75.0	Trace	
	11/18/68			0.4	16.5	79.6	0	
	12/17/68			2.1	20.0	77.1	0	
	1/15/69			0.4	21.3	78.8	0	
	2/28/69			1.4	17.9	81.5	0	
	9/17/69			0	21.7	80.0	0	
	11/5/69			3.8	20.5	77.8	0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 8

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
19A	5/9/67			28.6	0.8	41.3	30.2	
	9/13/67			8.3	15.5	75.0	Trace	
	11/18/68			Trace	18.9	81.6	0	
	12/17/68			4.2	15.4	77.6	0	
	1/15/69			4.1	16.1	79.4	0	
	2/28/69			8.8	3.2	91.5	0	
	9/17/69			0	20.4	77.4	0	
	11/5/69			4.9	19.2	76.6	0	
19B	5/9/67			30.2	0.7	30.7	39.5	
	9/13/67			12.8	12.0	73.5	0.0	
	11/18/68			1.1	14.5	80.9	0	
	12/17/68			2.6	19.0	76.8	0	
	1/15/69			6.2	15.3	79.1	0	
	2/28/69			7.5	6.8	85.6	0.7	
	9/17/69			5.6	18.5	77.6	0	
	11/5/69			6.3	17.9	75.8	0	
20A	5/9/67			27.4	1.2	47.0	24.5	
	9/13/67			12.6	9.8	73.5	0.1	
	11/18/68			2.3	9.3	82.3	0	
	12/17/68			1.7	19.3	76.5	0	
	1/15/69			3.5	17.8	80.2	0	
	2/28/69			10.5	1.0	88.0	1.1	
	9/17/69			-	-	-	-	
	11/5/69			Destroyed				
20B	5/9/67			27.2	0.8	44.3	27.0	
	9/13/67			15.9	7.0	74.0	0.0	
	11/18/68			3.6	7.4	81.3	0	
	12/17/68			4.2	16.8	76.2	0	
	1/15/69			3.4	17.7	79.1	0	
	2/28/69			10.4	4.1	84.9	2.0	
	9/17/69			-	-	-	-	
	11/5/69			Destroyed				
22A	5/9/67			5.8	15.5	76.3	Nil	
	9/13/67			6.2	17.9	74.0	Trace	
	11/18/68			0.3	18.5	80.0	0	
	12/17/68			2.4	20.5	76.4	0	
	1/15/69			1.3	20.2	79.2	0	
	2/28/69			0.8	18.3	81.5	0	
	9/17/69			0.4	19.7	78.9	0	
	11/5/69			4.9	17.9	75.8	0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 8

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
23A	5/9/67			7.5	13.8	77.5	Trace	
	9/13/67			8.8	15.2	75.0	0.0	
	11/18/68			Trace	18.5	81.8	0	
	12/17/68			4.2	17.7	76.4	0	
	1/15/69			3.0	17.9	78.8	0	
	2/28/69			3.4	15.7	83.6	0	
	9/17/69			5.5	13.9	78.0	0	
	11/5/69			0	22.2	75.8	0	
24A	5/9/67			6.8	14.3	75.5	Nil	
	9/13/67			7.2	16.3	75.5	0.0	
	11/18/68			-	-	-	-	
	12/17/68			-	-	-	-	
	1/15/69			-	-	-	-	
	2/28/69			-	-	-	-	
	9/17/69			-	-	-	-	
	11/5/69			Destroyed				
25	5/9/67			39.0	0.3	4.1	57.2	In Manhole
	9/13/67			38.0	0.4	5.6	55.5	
	11/18/68			37.7	0	13.1	50.5	
	12/17/68			-	-	-	-	
	1/15/69			-	-	-	-	
	2/28/69			-	-	-	-	
	9/17/69			31.3	4.4	21.0	43.7	
	11/5/69			31.9	5.1	21.0	44.0	
26	5/9/67			44.6	0.2	2.0	54.0	In Manhole
	9/13/67			-	-	-	-	
	11/18/68			-	-	-	-	
	12/17/68			-	-	-	-	
	1/15/69			-	-	-	-	
	2/28/69			-	-	-	-	
	9/17/69			33.3	2.8	20.3	40.0	
	11/5/69			32.6	4.1	22.6	41.8	
27	5/9/67			26.0	5.3	27.3	42.3	In Manhole
	9/13/67			8.4	15.4	69.0	5.7	
	11/18/68			0.4	17.0	78.7	1.0	
	12/17/68			2.5	19.5	76.0	0	
	1/15/69			3.7	17.3	79.8	0	
	2/28/69			13.3	12.6	63.5	13.3	
	9/17/69			7.3	14.2	75.0	1.5	
	11/5/69			1.4	19.7	83.4	0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 8

(Percent by Volume)

Probe	Date	Temp oF	Weather	CO_2	O_2	N_2	CH_4	Remarks
28	5/9/67			30.7	0.6	24.4	44.0	In Manhole
	9/13/67			-	-	-	-	
	11/18/68			-	-	-	-	
	12/17/68			-	-	-	-	
	1/15/69			-	-	-	-	
	2/28/69			-	-	-	-	
	9/17/69			11.5	10.1	69.7	4.5	
	11/5/69			21.5	2.1	68.5	6.0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
1	7/24/67	82	Windy,Clear Warm	15	12	71	0	
	11/28/67	55	Cloudy-Showers	7	11	81	0	
	6/28/68	-	Warm	3.2	19	78	0	
	1/13/69	61	Light Rain	1.9	18	79	0	
	7/28/69	78	Clear	Destroyed				
	10/29/69			Destroyed				
2	7/24/67			21	6	73	0	
	11/28/67			14	8	76	0	
	6/28/68			3.6	17	78	0	
	1/13/69			3.4	17	79	0	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
3	7/24/67			23	2	72	0.8	
	11/28/67			15	7	76	0	
	6/28/68			5	16	78	0	
	1/13/69			7	15	79	0	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
4	7/24/67			26	1.1	65	5	
	11/28/67			26	1.5	44	28	
	6/28/68			10	12	76	0	
	1/13/69			14	9	79	0	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
5	7/24/67			33	0.8	48	17	
	11/28/67			30	0.3	10	58	
	6/28/68			13	8	78	0	
	1/13/69			24	1.0	70	7	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
6	7/24/67			40	0.3	19	42	
	11/28/67		–	26	3.0	22	50	
	6/28/68			27	0.4	38	34	
	1/13/69			29	0.5	37	36	
	7/28/69			Destroyed				
	10/29/69			Destroyed				

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
7	7/24/67			38	0.4	24	37	
	11/28/67			31	0.3	7	61	
	6/28/68			12	7	79	0	
	1/13/69			31	0.6	41	28	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
8	7/24/67			34	1.0	47	19	
	11/28/67			31	0.3	28	40	
	6/28/68			33	0.5	45	22	
	1/13/69			32	1.4	48	20	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
9	7/24/67			36	0.4	33	30	
	11/28/67			33	0.4	21	45	
	6/28/68			34	0.5	40	26	
	1/13/69			29	3.7	43	23	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
10	7/24/67			44	0.5	11	45	
	11/28/67			35	0.1	5.6	60	
	6/28/68			38	0.2	13	49	
	1/13/69			37	0.3	12	50	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
11	7/24/67			32	0.6	42	27	
	11/28/67			32	0.1	7	63	
	6/28/68			29	0.4	31	39	
	1/13/69			27	0.4	29	45	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
12	7/24/67			42	0.4	19	41	
	11/28/67			31	0.2	17	54	
	6/28/68			31	0.4	33	36	
	1/13/69			30	0.4	37	34	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
13	7/24/67			Plugged				
	11/28/67			Plugged				

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
13	6/28/68			Plugged				
	1/13/69			Plugged				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
14	7/24/67			37	0.6	35	26	
	11/28/67			29	0.1	22	48	
	6/28/68			28	0.8	56	16	
	1/13/69			27	0.9	54	20	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
15	7/24/67			12	11	76	0	
	11/28/67			25	0.6	42	32	
	6/28/68			Lost				
	1/13/69			Lost				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
16	7/24/67			34	0.8	46	20	
	11/28/67			29	0.2	21	52	
	6/28/68			27	0.6	50	23	
	1/13/69			22	1.5	51	24	
	7/28/69			59	0.7	22	18	
	10/29/69			Destroyed				
17	7/24/67			39	0.4	24	37	
	11/28/67			27	0.3	12	63	
	6/28/68			32	0.4	30	39	
	1/13/69			30	0.2	17	51	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
18	7/24/67			39	0.3	15	46	
	11/28/67			28	0.1	10	64	
	6/28/68			32	0.2	13	55	
	1/13/69			29	0.3	20	51	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
19	7/24/67			39	0.5	17	45	
	11/28/67			29	0.1	13	58	
	6/28/68			34	0.4	28	40	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
19	1/13/69			30	0.4	33	39	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
20	7/24/67			38	0.4	26	33	
	11/28/67			31	0.3	10	61	
	6/28/68			33	0.3	24	44	
	1/13/69			33	0.3	18	48	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
21	7/24/67			37	0.3	18	43	
	11/28/67			34	0.2	7	59	
	6/28/68			35	0.2	16	50	
	1/13/69			32	0.5	24	45	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
22	7/24/67			35	0.2	7	58	
	11/28/67			20	3.3	22	53	
	6/28/68			31	0.2	16	55	
	1/13/69			28	0.5	25	46	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
23	7/24/67			39	0.4	3	57	
	11/28/67			37	0.1	1.2	61	
	6/28/68			41	0.1	2.3	57	
	1/13/69			41	0.2	3.6	53	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
24	7/24/67			38	0.5	31	29	
	11/28/67			33	0.5	18	48	
	6/28/68			33	0.7	42	25	
	1/13/69			34	1.1	40	26	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
25	7/24/67			44	0.1	1.5	55	
	11/28/67			38	0.1	3.9	57	
	6/28/68			43	0.1	5	51	
	1/13/69			40	1.9	10	46	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
25	7/28/69			53	1.4	12	34	
	10/29/69			43	0.8	7.0	51	
26	7/24/67			38	0.4	20	40	
	11/28/67			34	0.8	11	56	
	6/28/68			37	0.3	19	45	
	1/13/69			40	0.2	10	50	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
27	7/24/67			31	0.7	38	28	
	11/28/67			29	0.4	20	51	
	6/28/68			28	0.5	36	35	
	1/13/69			32	0.2	22	46	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
28	7/24/67			37	0.4	19	42	
	11/28/67			30	0.3	27	44	
	6/28/68			36	0.4	27	39	
	1/13/69			36	0.3	25	38	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
29	7/24/67			36	0.5	29	32	
	11/28/67			29	0.5	23	49	
	6/28/68			35	0.4	34	33	
	1/13/69			37	0.4	28	37	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
30	7/24/67			34	0.6	35	29	
	11/28/67			33	0.3	17	51	
	6/28/68			34	0.6	34	33	
	1/13/69			37	0.2	18	44	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
31	7/24/67			39	0.3	18	43	
	11/28/67			34	0.1	7	60	
	6/28/68			34	0.4	25	43	
	1/13/69			35	0.2	11	53	
	7/28/69			57	0.8	15	29	
	10/29/69			38	1.1	6.6	52	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
32	7/24/67			34	0.5	35	30	
	11/28/67			34	0.1	7	60	
	6/28/68			34	0.4	25	43	
	1/13/69			Lost				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
33	7/24/67			-	-	-	-	
	11/28/67			33	0.3	18	51	
	6/28/68			30	0.5	45	27	
	1/13/69			35	0.3	26	40	
	7/28/69			34	0.6	17	46	
	10/29/69			35	1.6	20	43	
34	7/24/67			-	-	-	-	
	11/28/67			35	0.2	7	58	
	6/28/68			37	0.2	14	50	
	1/13/69			41	0.1	6	51	
	7/28/69			29	4.5	21	47	
	10/29/69			42	1.6	2.9	53	
35	7/24/67			-	-	-	-	
	11/28/67			35	0.1	9	57	
	6/28/68			36	0.2	17	47	
	1/13/69			39	0.2	14	46	
	7/28/69			33	2.9	27	36	
	10/29/69			37	3.0	13	46	
36	7/24/67			-	-	-	-	
	11/28/67			34	0.1	9	57	
	6/28/68			36	0.3	21	44	
	1/13/69			37	0.2	16	45	
	7/28/69			31	1.0	13	54	
	10/29/69			37	2.3	20	41	
37	7/24/67			-	-	-	-	
	11/28/67			-	-	-	-	
	6/28/68			35	0.3	30	37	
	1/13/69			38	0.2	18	44	
	7/28/69			31	0.7	18	51	
	10/29/69			39	1.4	17	43	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
38	7/24/67			-	-	-	-	
	11/28/67			32	0.1	5.2	62	
	6/28/68			34	0.2	17	48	
	1/13/69			33	0.5	23	43	
	7/28/69			28	0.8	5.8	66	
	10/29/69			Lost				
39	7/24/67			-	-	-	-	
	11/28/67			28	0.1	8	66	
	6/28/68			26	0.4	32	44	
	1/13/69			27	0.4	37	37	
	7/28/69			20	8.8	39	34	
	10/29/69			29	2.9	13	53	Contained Water
40	7/24/67			-	-	-	-	
	11/28/67			27	0.2	14	59	
	6/28/68			25	0.6	46	30	
	1/13/69			26	0.4	40	34	
	7/28/69			33	0.4	5.5	63	
	10/29/69			36	0.7	5.6	59	
41	7/24/67			-	-	-	-	
	11/28/67			27	0.4	23	50	
	6/28/68			Lost				
	1/13/69			Lost				
	7/28/69			38	0.8	10	49	
	10/29/69			-	-	-	-	
42	7/24/67			-	-	-	-	
	11/28/67			26	0.4	29	47	
	6/28/68			21	0.8	69	9	
	1/13/69			6	15	79	0	
	7/28/69			31	0.9	12	58	
	10/29/69			31	2.3	10	56	
47	7/24/67			33	0.6	26	39	
	11/28/67			27	0.3	20	55	
	6/28/68			27	0.6	43	31	
	1/13/69			24	0.4	53	24	
	7/28/69			Destroyed				
	10/29/69			Destroyed				

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
48	7/24/67			36	0.4	24	40	
	11/28/67			31	0.2	12	59	
	6/28/68			29	0.7	34	38	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
49	7/24/67			33	0.6	32	33	
	11/28/67			30	0.2	14	57	
	6/28/68			26	0.6	50	25	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
50	7/24/67			37	0.4	21	41	
	11/28/67			30	0.2	5.4	65	
	6/28/68			31	0.4	30	40	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
51	7/24/67			30	0.5	29	41	
	11/28/67			28	0.4	15	56	
	6/28/68			22	0.6	42	37	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
52	7/24/67			36	0.3	19	46	
	11/28/67			26	0.4	29	46	
	6/28/68			24	0.7	54	23	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
53	7/24/67			38	0.3	11	52	
	11/28/67			29	0.2	17	55	
	6/28/68			28	0.6	35	38	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
54	7/24/67			30	0.5	28	41	
	11/28/67			26	0.4	26	48	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
54	6/28/68			22	0.9	64	12	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
55	7/24/67			34	0.4	17	50	
	11/28/67			22	0.5	41	36	
	6/28/68			7	12	79	0	
	1/13/69			2.1	21	75	0	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
56	7/24/67			35	0.3	16	48	
	11/28/67			22	0.5	41	37	
	6/28/68			10	11	77	0	
	1/13/69			2.2	20	76	0	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
57	7/24/67			31	0.5	30	38	
	11/28/67			16	1.0	68	14	
	6/28/68			8	13	77	0	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
58	7/24/67			29	0.7	47	22	
	11/28/67			20	0.9	62	17	
	6/28/68			5	15	79	0	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
59	7/24/67			36	0.4	25	39	
	11/28/67			25	0.5	35	41	
	6/28/68			12	9	79	0	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
60	7/24/67			37	0.3	18	45	
	11/28/67			23	0.6	48	28	
	6/28/68			4.1	18	77	0	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
60	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
61	7/24/67			28	0.9	56	17	
	11/28/67			17	3.4	78	0.1	
	6/28/68			3.2	19	77	0	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
62	7/24/67			4.8	17	77	0	
	11/28/67			4.5	18	77	0	
	6/28/68			Lost				
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
63	7/24/67			2.3	20	76	0	
	11/28/67			3.6	18	77	0	
	6/28/68			0.9	20	78	0	
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
64	7/24/67			1.2	20	76	0	
	11/28/67			1.6	19	79	0	
	6/28/68			Lost				
	1/13/69			Destroyed				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
65	7/24/67			-	-	-	-	
	11/28/67			-	-	-	-	
	6/28/68			Plugged				
	1/13/69			Plugged				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
66	7/24/67			-	-	-	-	
	11/28/67			25	0.5	33	44	
	6/28/68			22	0.9	60	15	
	1/13/69			Plugged				

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
66	7/28/69			0.5	21	77	0	
	10/29/69			0	20	79	0	
67	7/24/67			-	-	-	-	
	11/28/67			18	0.4	61	20	
	6/28/68			0.6	20	78	0	
	1/13/69			0.2	21	78	0	
	7/28/69			Destroyed				
	10/29/69			Destroyed				
68	7/24/67			-	-	-	-	
	11/28/67			5.3	14	79	0	
	6/28/68			Plugged				
	1/13/69			Plugged				
	7/28/69			Destroyed				
	10/29/69			Destroyed				
69	7/24/67			-	-	-	-	
	11/28/67			-	-	-	-	
	6/28/68			27	2.6	57	15	
	1/13/69			Lost				
	7/28/69			0.6	18	81	0	
	10/29/69			-	-	-	-	
70	7/24/67			-	-	-	-	
	11/28/67			-	-	-	-	
	6/28/68			36	0.4	20	46	
	1/13/69			Plugged				
	7/28/69			34	0.8	3.6	60	
	10/29/69			36	2.0	9.1	51	Water in Probe
71	7/24/67			-	-	-	-	
	11/28/67			-	-	-	-	
	6/28/68			39	0.2	13	49	
	1/13/69			40	0.1	6	52	
72	7/24/67			-	-	-	-	
	11/28/67			-	-	-	-	
	6/28/68			39	0.2	11	51	
	1/13/69			31	0.2	18	49	
	7/28/69			26	1.7	4.8	66	
	10/29/69			41	1.0	1.0	59	

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 9

(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	Remarks
73	7/24/67			-	-	-	-	
	11/28/67			-	-	-	-	
	6/28/68			33	0.3	25	44	
	1/13/69			26	0.6	45	27	
	7/28/69			30	1.1	4.6	65	
	10/29/69			35	1.3	1.9	60	Water in Probe
74	7/24/67			-	-	-	-	
	11/28/67			-	-	-	-	
	6/28/68			27	0.7	54	19	
	1/13/69			12	6	80	1.0	
	7/28/69			-	-	-	-	
	10/29/69			30	3.7	9.8	56	
75	7/24/67			-	-	-	-	
	11/28/67			-	-	-	-	
	6/28/68			24	0.8	62	14	
	1/13/69			23	0.8	61	14	
	7/28/69			-	-	-	-	
	10/29/69			38	1.2	4.5	54	Water in Probe

GAS ANALYSIS DATA
PROJECT SUMMARY
SITE 10

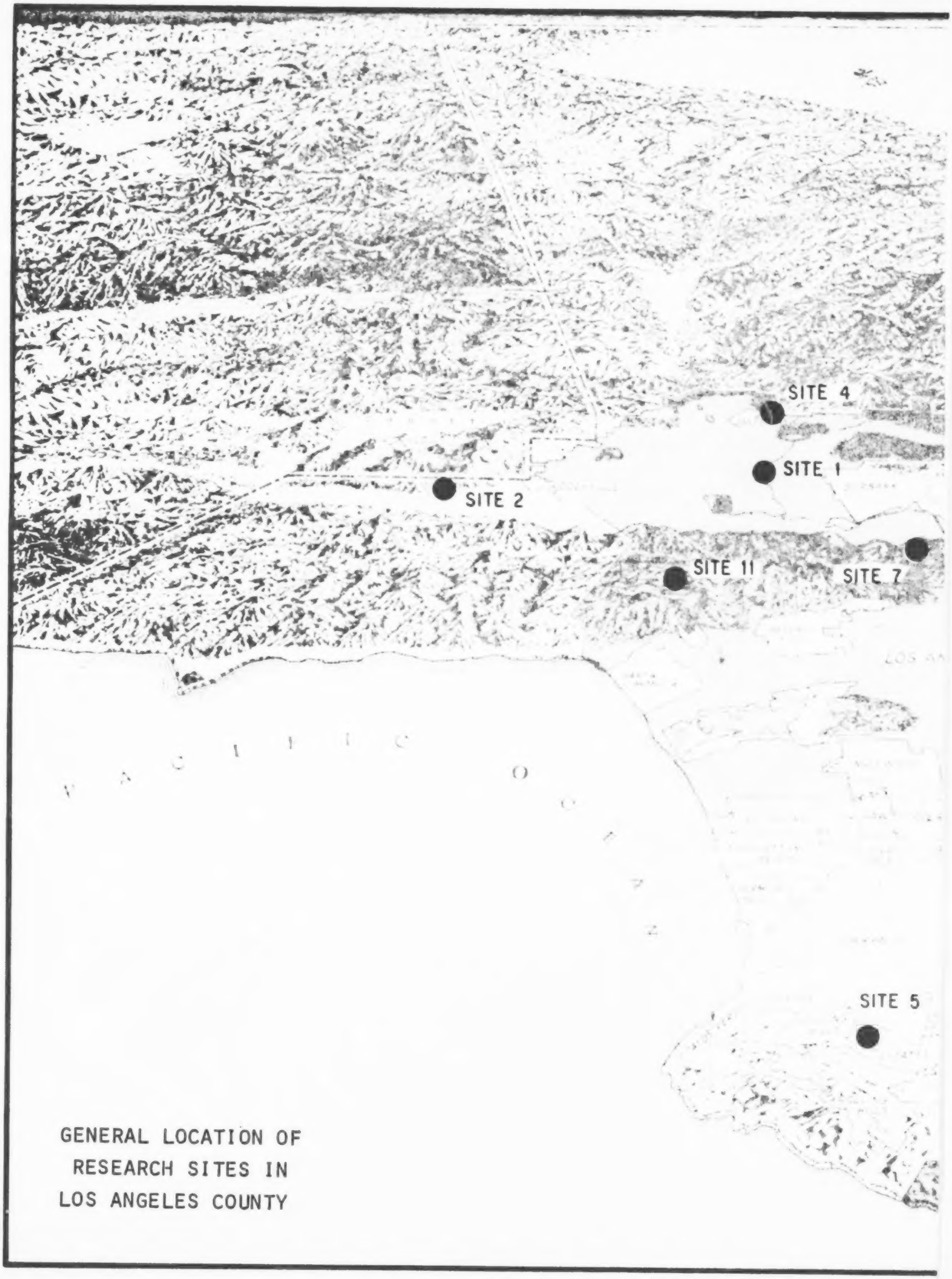
(Percent by Volume)

Probe	Date	Temp °F	Weather	CO_2	O_2	N_2	CH_4	H_2S
	10/15/67	70	Clear					
1				32.4	0.5	24.7	43.3	0.1
2				10.2	6.0	74.5	0.1	0.1
3				34.9	0.1	3.9	59.3	0.1
4				32.0	2.3	23.2	42.3	Trace
5				7.8	15.0	74.0	0.7	0.0
6				20.9	1.0	70.5	6.2	Trace
7				15.9	6.7	75.5	Trace	Trace
8				23.0	5.2	47.0	23.4	Trace
	11/4/67	67	Clear					
1				31.4	0.5	30.0	40.5	0.0
2				10.1	11.8	79.0	Trace	0.0
3				35.9	0.3	8.1	59.5	0.0
4				16.6	9.0	58.0	14.9	0.0
5				5.3	16.0	77.0	0.8	0.0
6				19.8	1.3	73.0	5.5	0.0
7				-	-	-	-	-
8				17.0	4.6	77.0	0.2	0.0

APPENDIX F

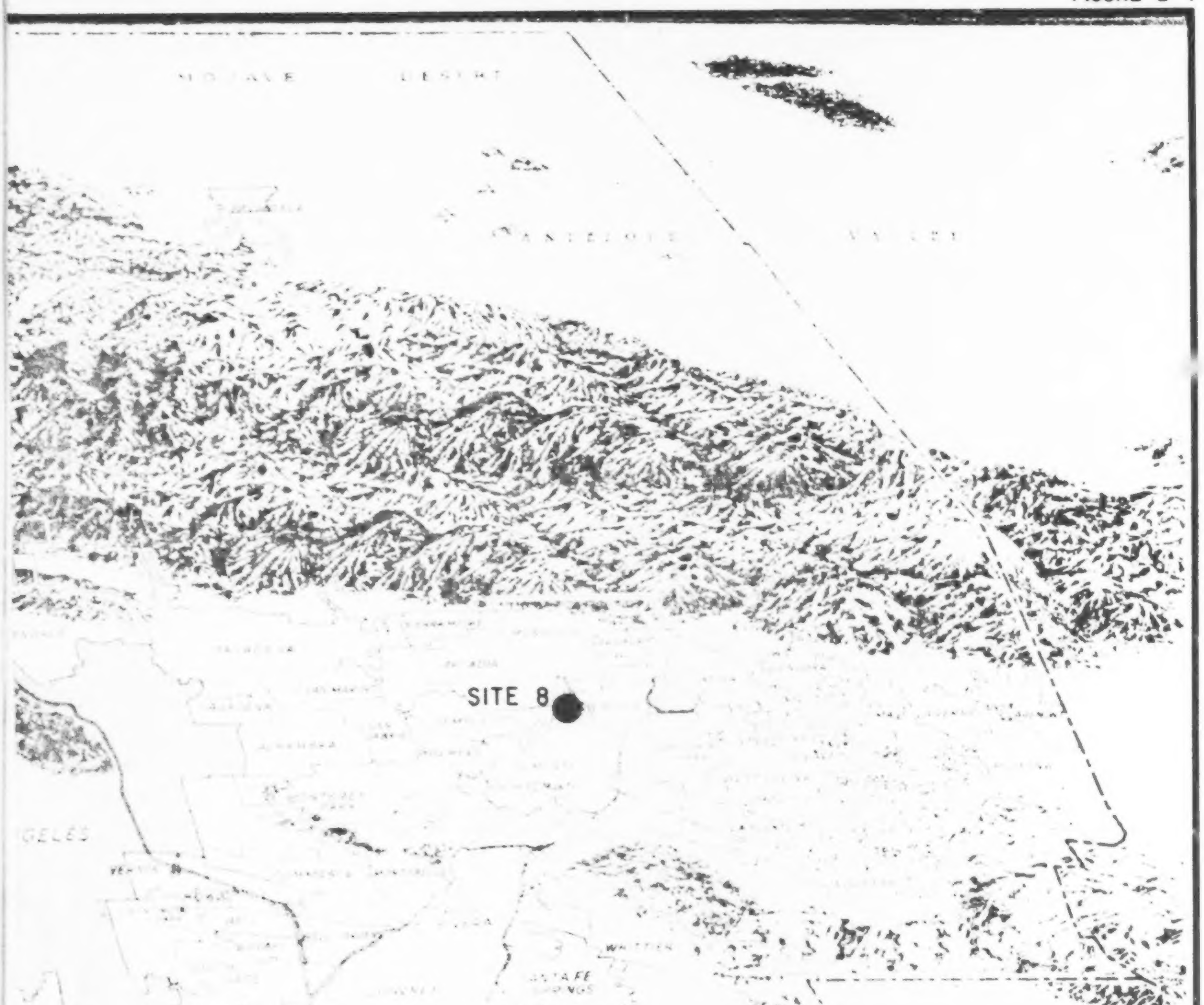
FIGURES

FIGURE I-1


SITE 4
SITE 1
SITE 2
SITE 11
SITE 7
SITE 5
PACIFIC OCEAN
LOS AN

GENERAL LOCATION OF RESEARCH SITES IN LOS ANGELES COUNTY

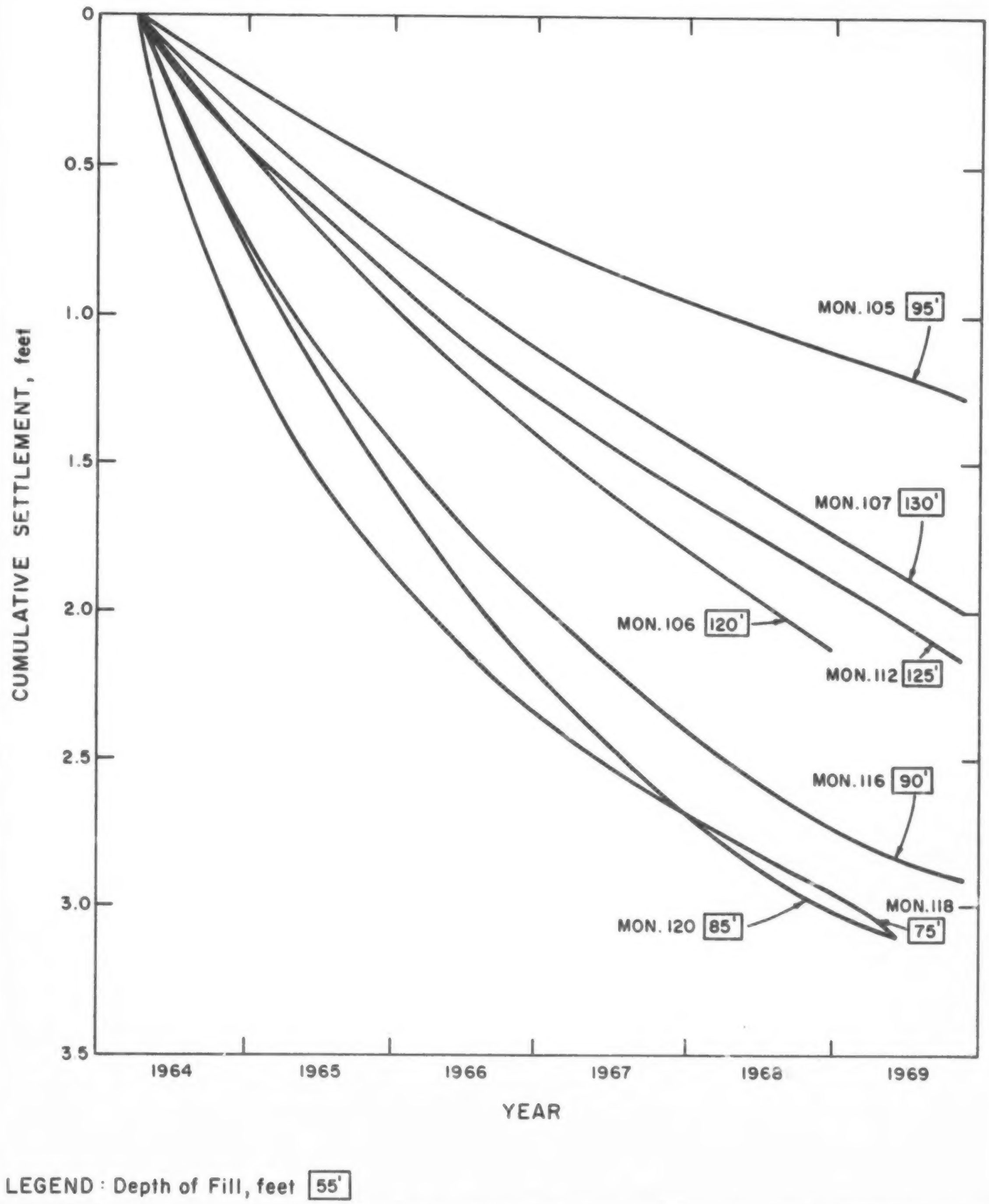
FIGURE I-1 (Cont'd)


MOJAVE DESERT
ANTELOPE VALLEY
SITE 8
SITE 6
SITE 3
WHITTIER
SANTA FE SPRINGS
NORWALK
BELLFLOWER
LAKEWOOD
ARTESIA
CERRITOS
LONG BEACH

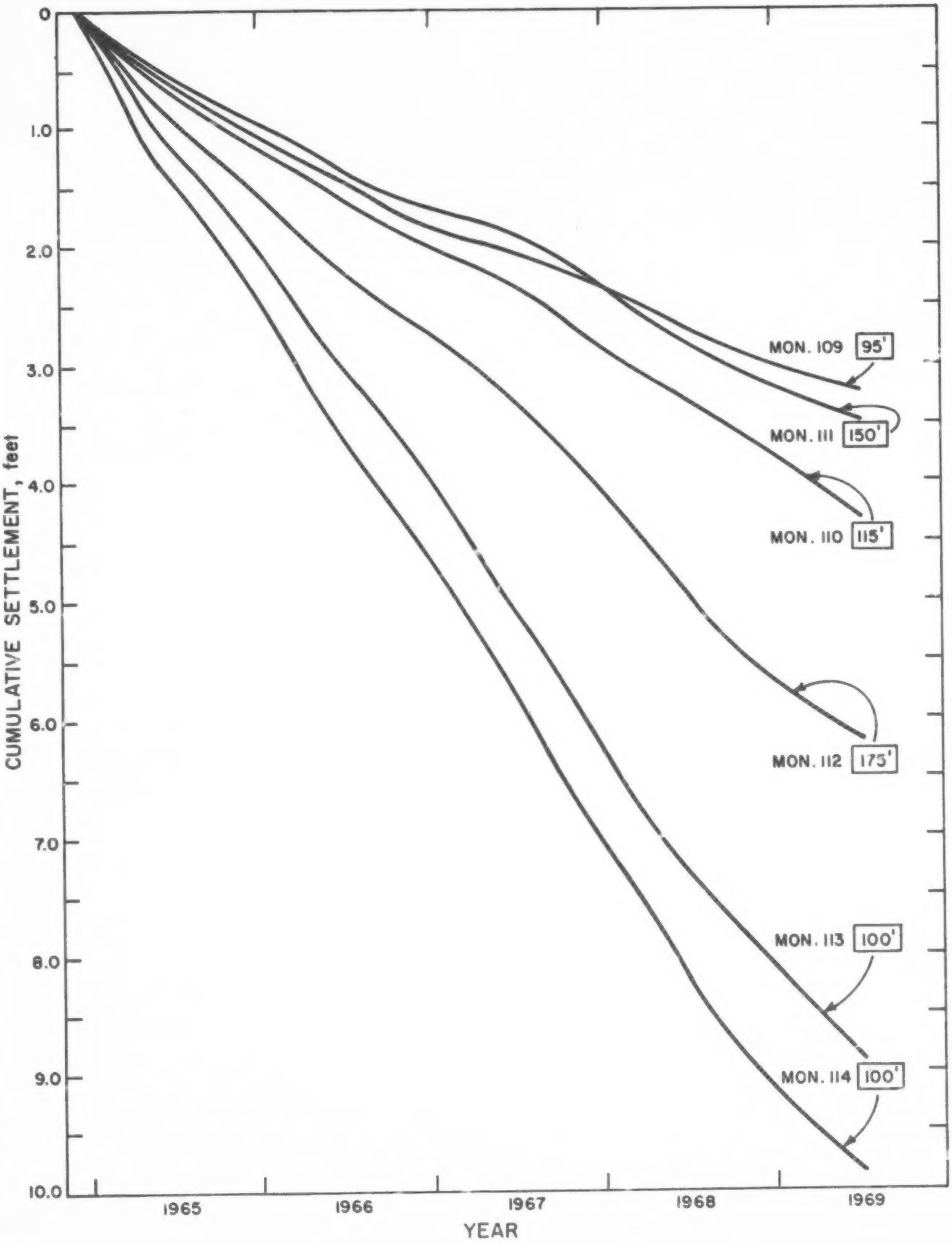
GENERAL LOCATION OF RESEARCH SITES IN LOS ANGELES COUNTY

FIGURE II-1

SETTLEMENT RECORD
SITE 5

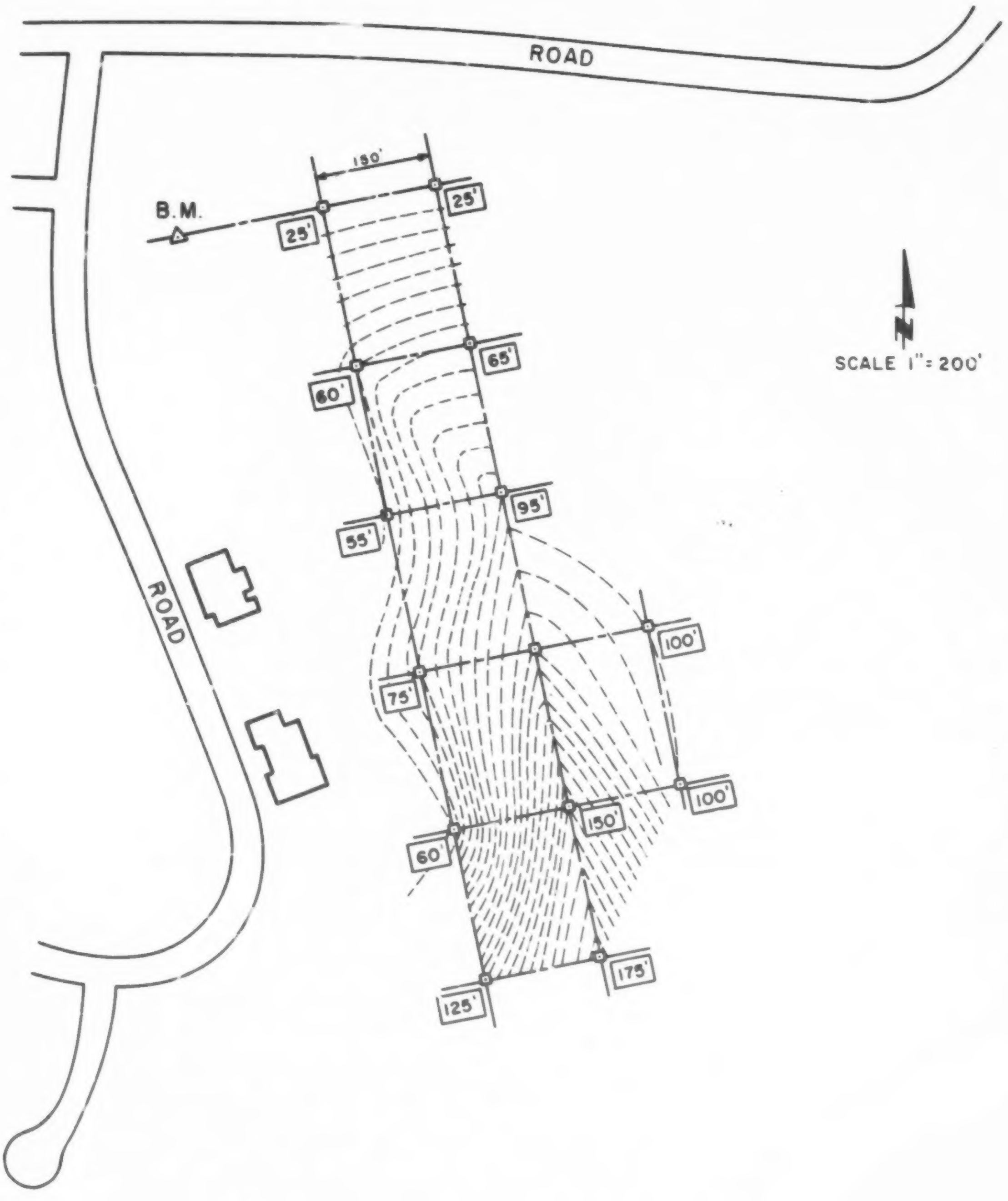


SETTLEMENT RECORD
AREA I
SITE II



LEGEND: Depth of Fill, feet 55'

FIGURE II-3

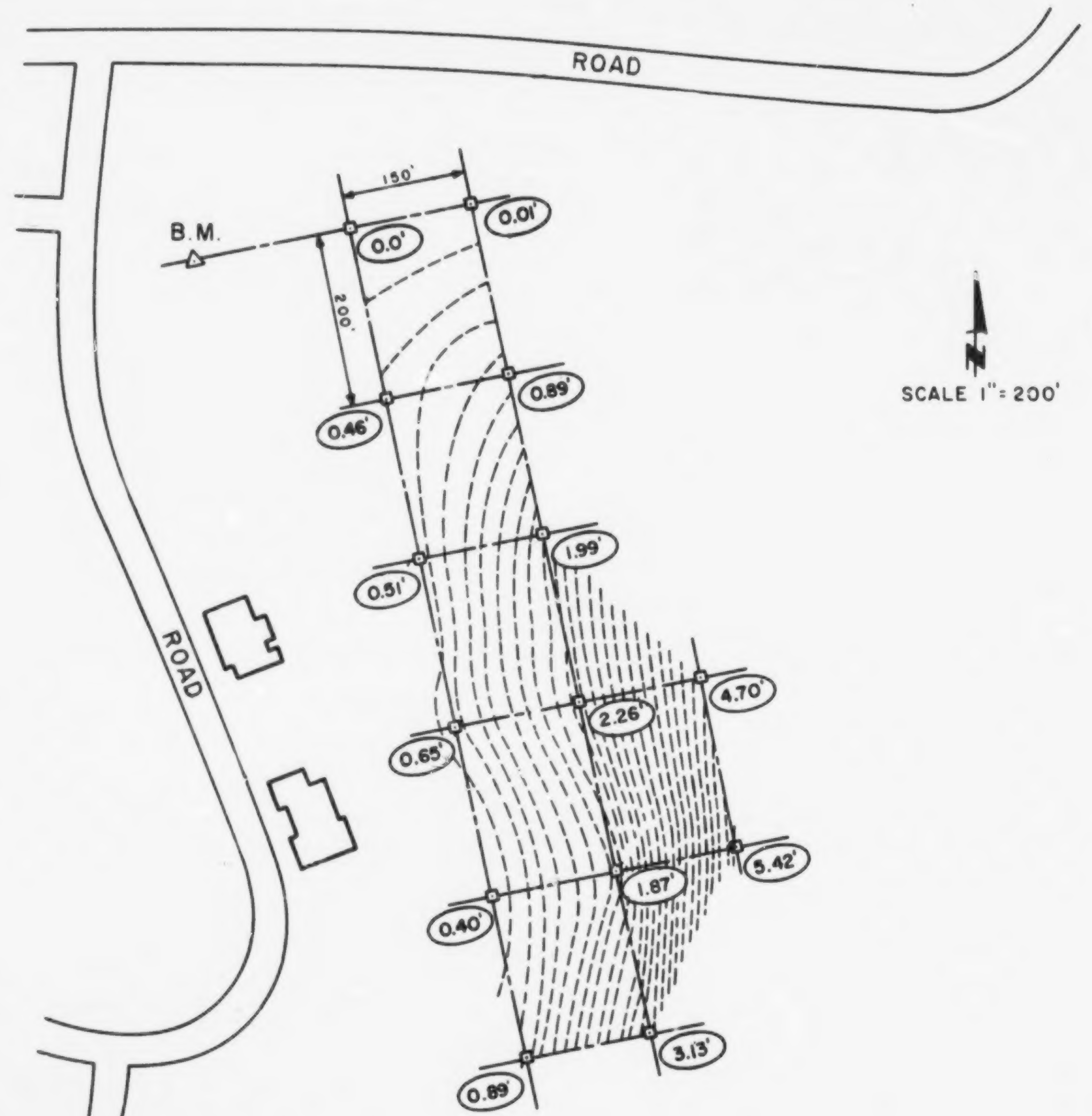

ROAD
ROAD
150'
B.M.
25'
25'
65'
60'
95'
55'
100'
75'
100'
150'
60'
175'
125'
N
SCALE 1" = 200'

LEGEND

Monument Location: ▫
Depth of Fill: 60'
Contour Interval: 5'

DEPTH OF FILL CURVES
AREA 1
SITE 11

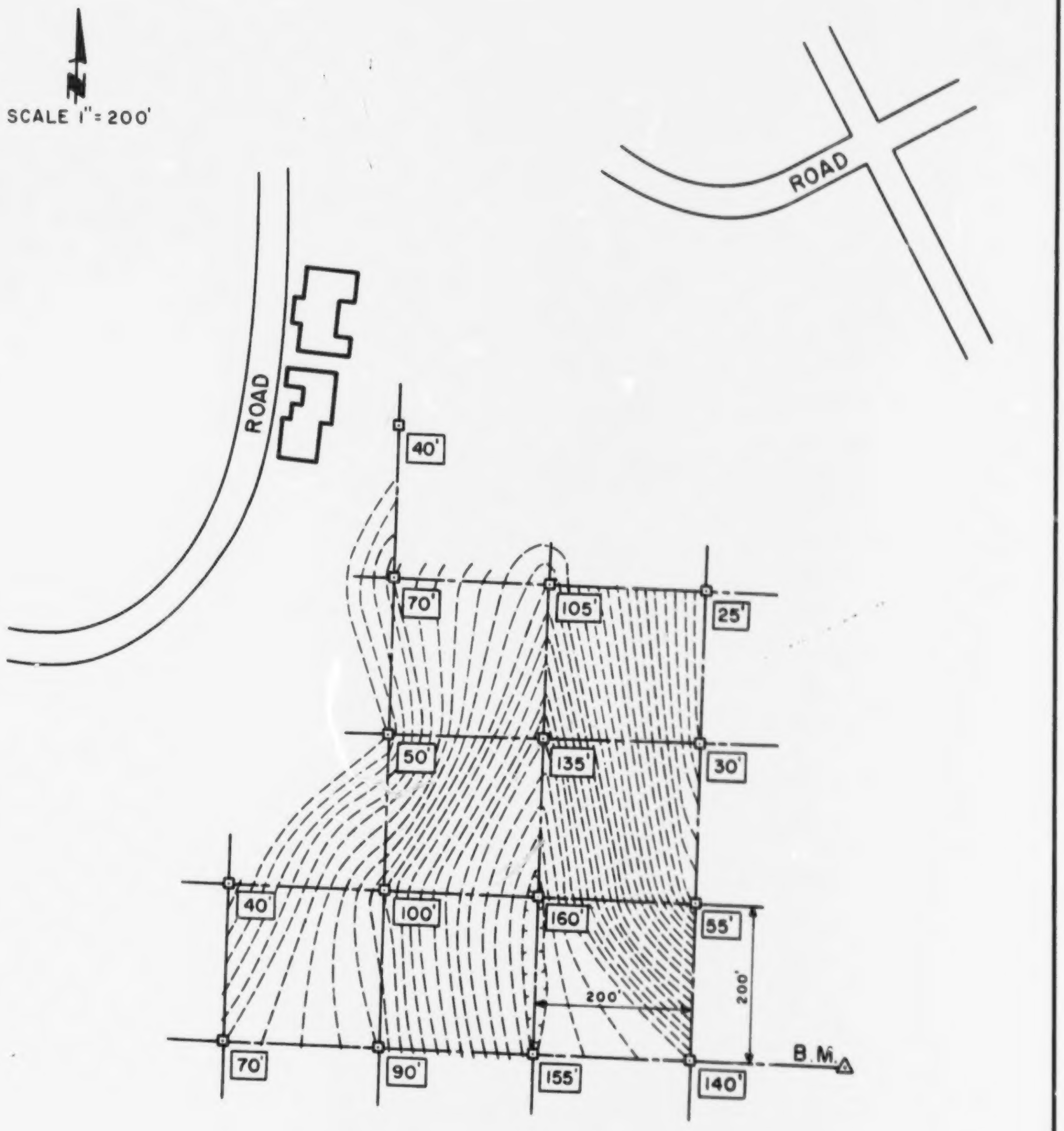
FIGURE II-4


ROAD
ROAD
B.M.
150'
200'
0.0'
0.01'
0.89'
0.46'
1.99'
0.51'
4.70'
2.26'
0.65'
5.42'
1.87'
0.40'
3.13'
0.89'
N
SCALE 1" = 200'

LEGEND

Monument Location : ◻
Cumulative Setlement: (0.60')
Contour Interval: 0.2'

CUMULATIVE SETTLEMENT
CURVES
AREA 1
SITE 11


N
SCALE 1" = 200'
ROAD
ROAD
40'
70'
105'
25'
50'
135'
30'
40'
100'
160'
55'
200'
200'
70'
90'
155'
140'
B.M.

LEGEND

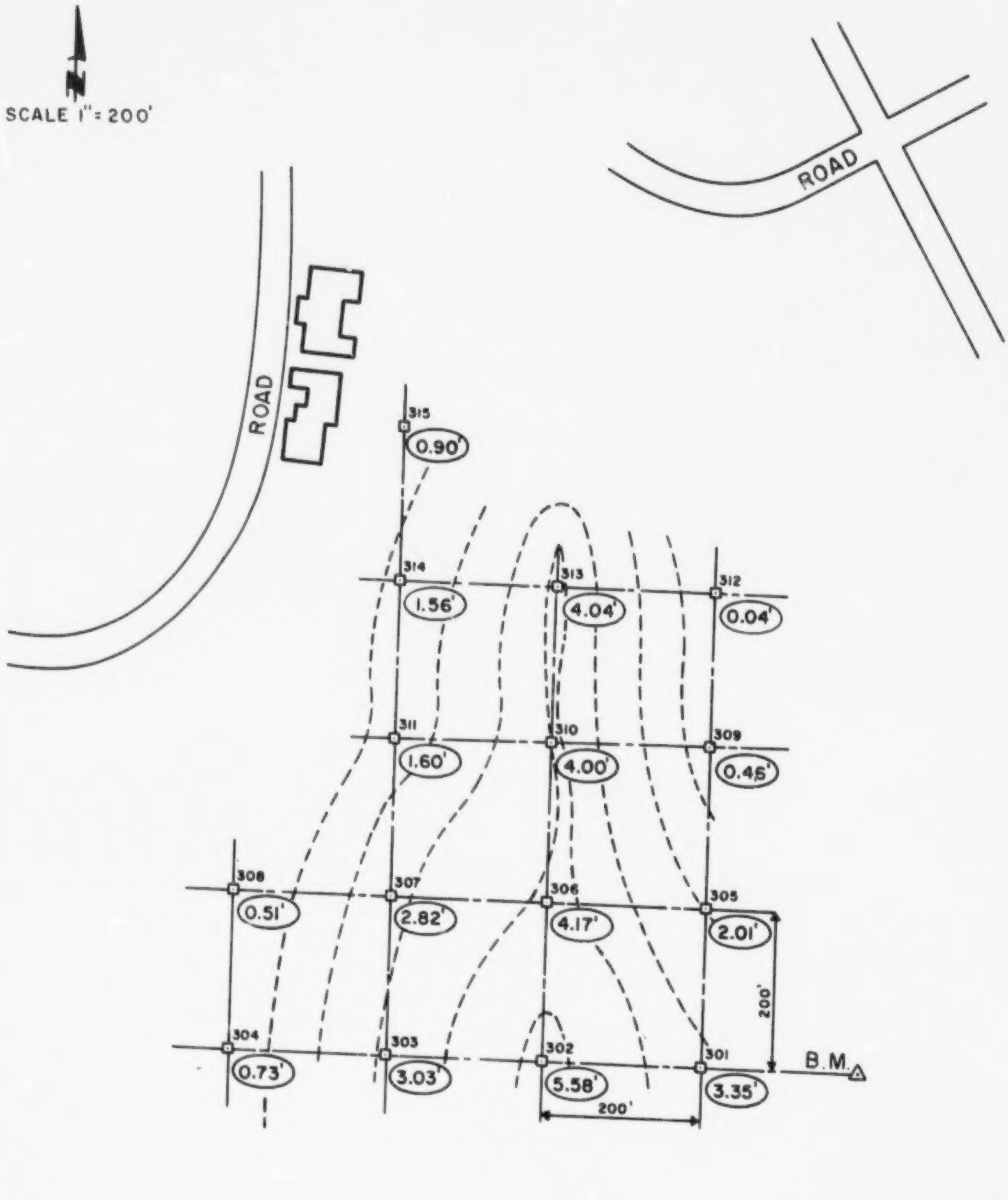
Monument Location: ▫

Depth of Fill: 60'

Contour Interval: 5'

DEPTH OF FILL CURVES
AREA 3
SITE 11

FIGURE II-6

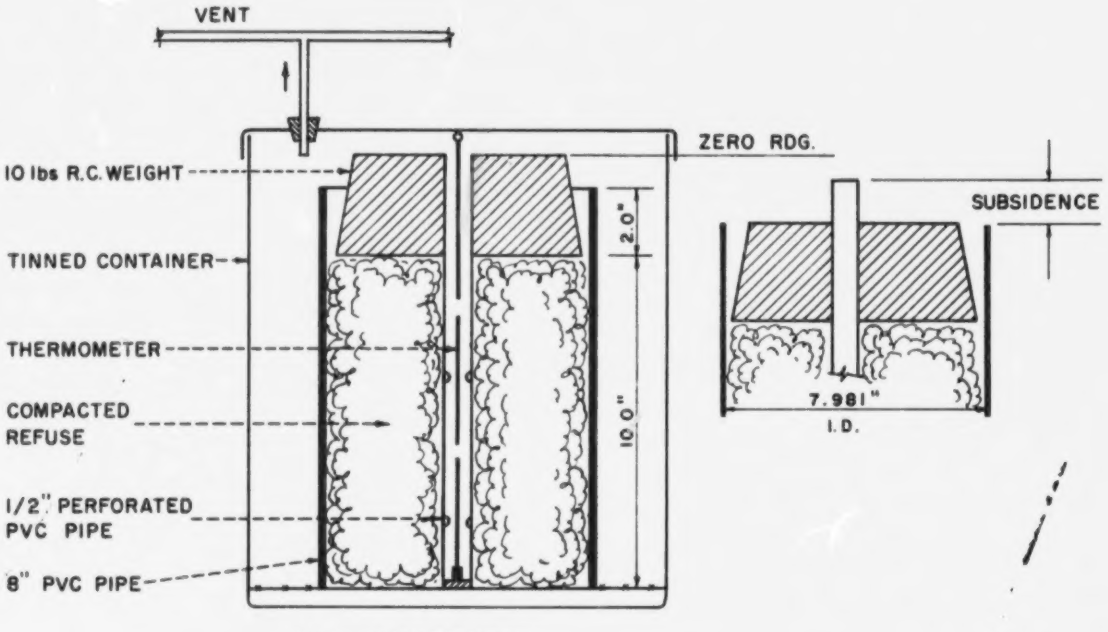

N
SCALE 1" = 200'
ROAD
ROAD
315
0.90'
314
1.56'
313
4.04'
312
0.04'
311
1.60'
310
4.00'
309
0.45'
308
0.51'
307
2.82'
306
4.17'
305
2.01'
304
0.73'
303
3.03'
302
5.58'
301
3.35'
200'
200'
B.M.

LEGEND
Monument Location: ⊡ 315
Cumulative Settlement Curves: (0.60')
Contour Interval: 0.1'

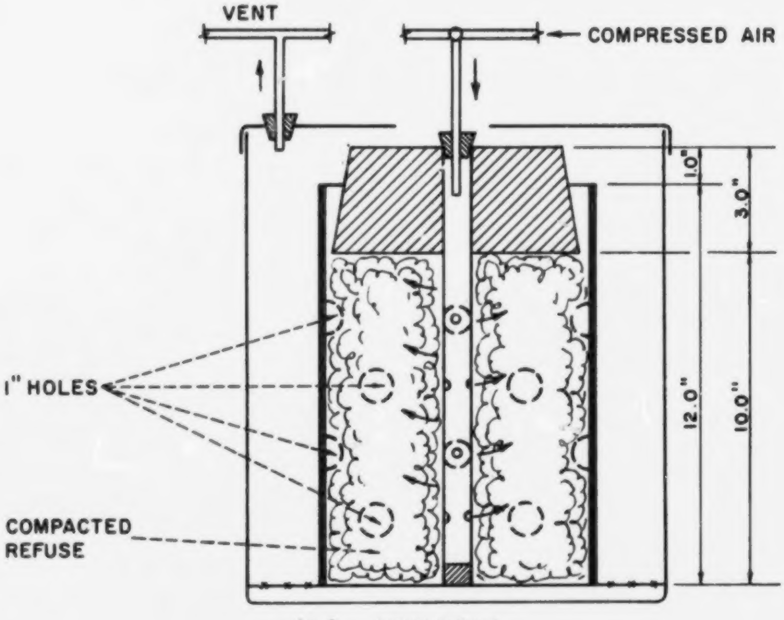
CUMULATIVE SETTLEMENT
CURVES
AREA 3
SITE 11

FIGURE II-7

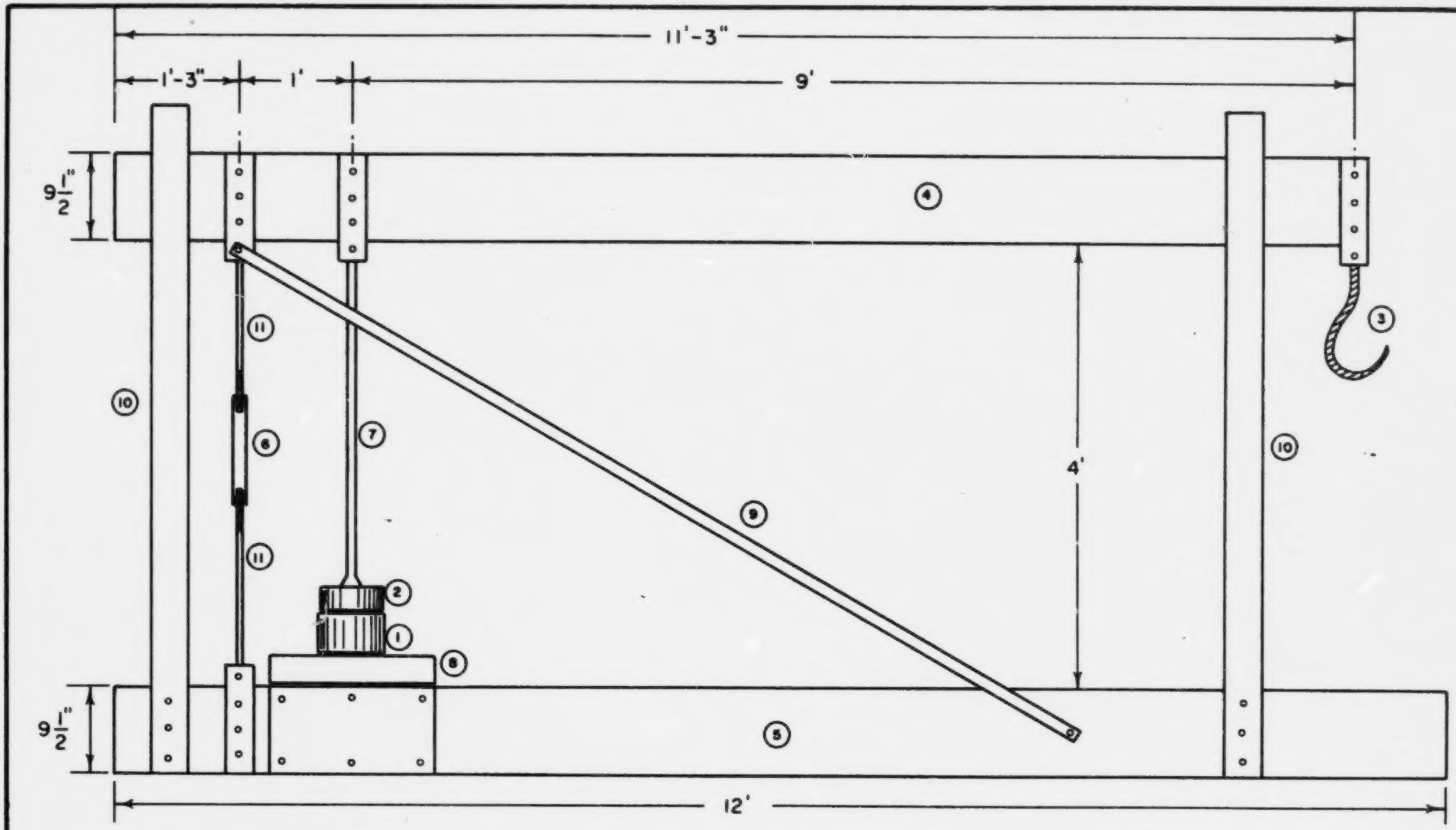
EXPERIMENTAL TEST UNITS


VENT
ZERO RDG.
10 lbs R.C. WEIGHT
SUBSIDENCE
TINNED CONTAINER
2.0"
THERMOMETER
COMPACTED REFUSE
7.981"
I.D.
10.0"
1/2" PERFORATED PVC PIPE
8" PVC PIPE

(a) ANAEROBIC


VENT
COMPRESSED AIR
1.0"
3.0"
1" HOLES
12.0"
10.0"
COMPACTED REFUSE

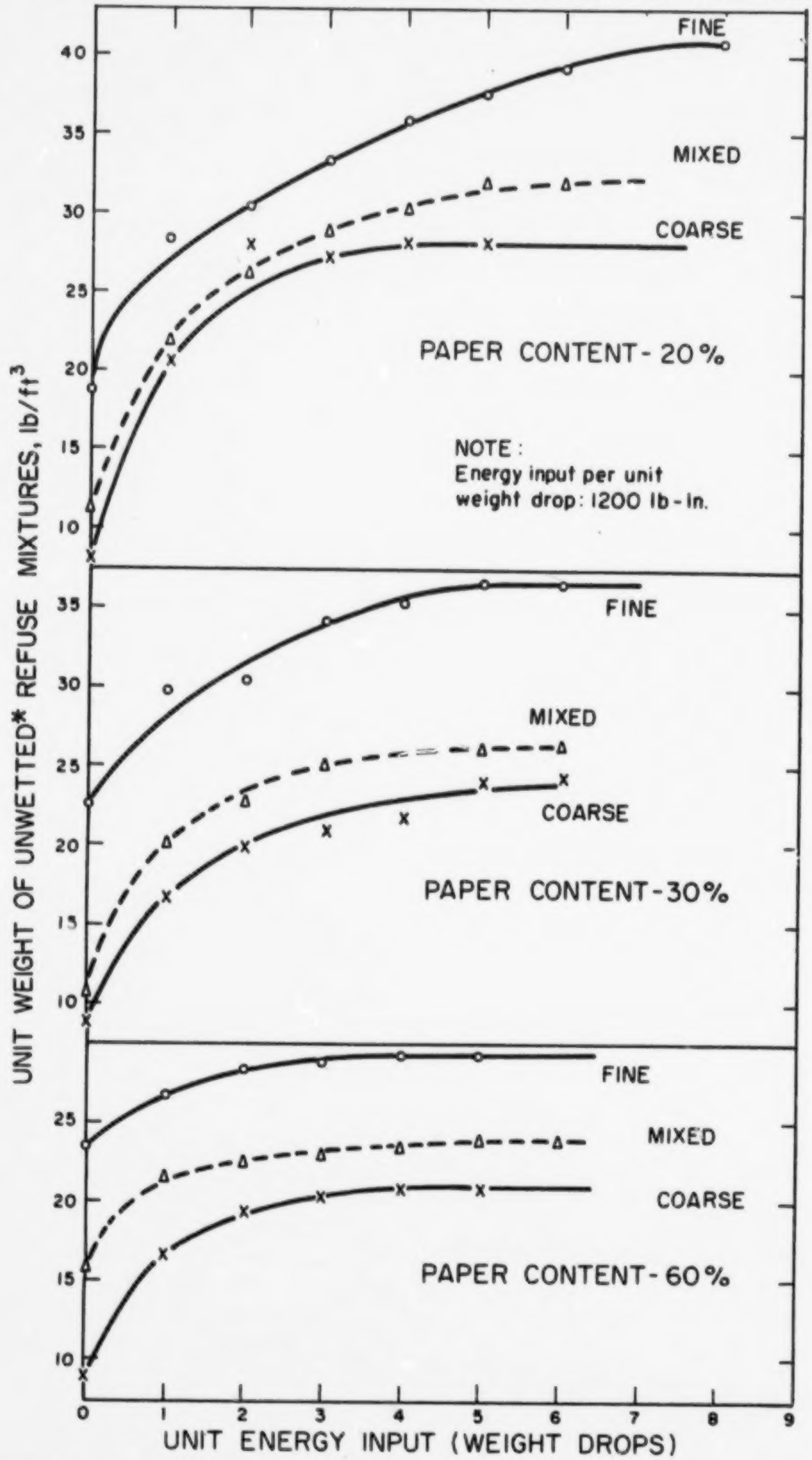
(b) AEROBIC


11'-3"
1'-3"
1'
9'
9½"
9½"
4'
12'
④
③
⑩
⑪
⑥
⑦
⑨
⑩
⑪
②
①
⑧
⑤

1. PRECONSOLIDATED SAMPLE
2. LOADING CYLINDER
3. LOADING HOOK
4. LEVER BEAM
5. BASE BEAM
6. TURNBUCKLE
7. PUSHING ROD
8. SAMPLE BASE
9. STIFFENERS
10. GUIDES
11. TENSION RODS

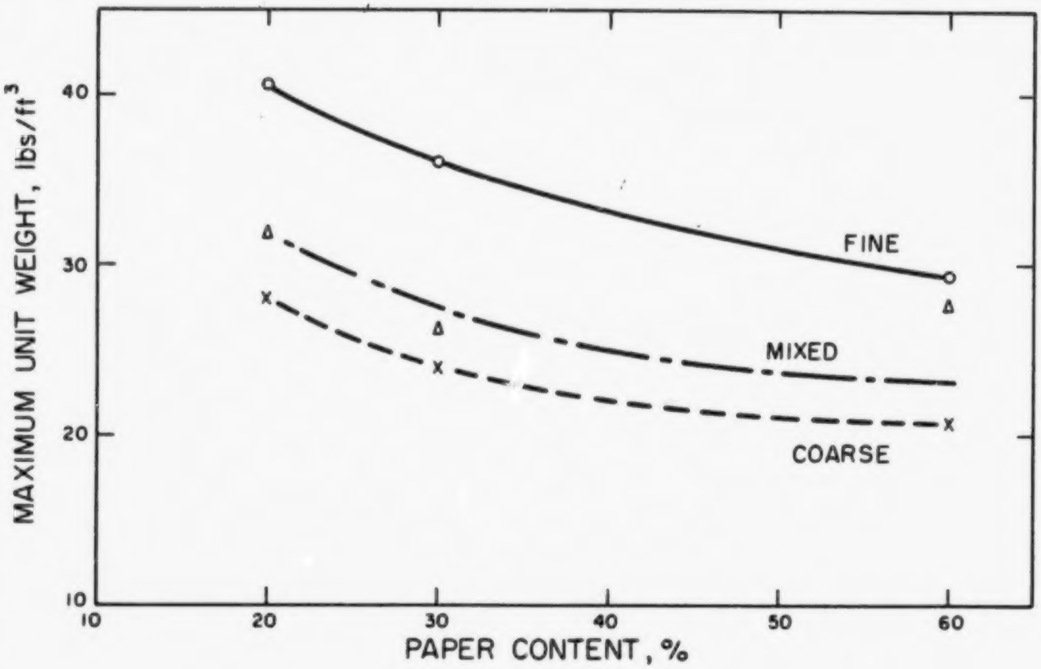
CONSOLIDATION TEST APPARATUS

INITIAL COMPACTION OF SYNTHETIC REFUSE CELLS



*See Table II-12 for Percent Water in Refuse

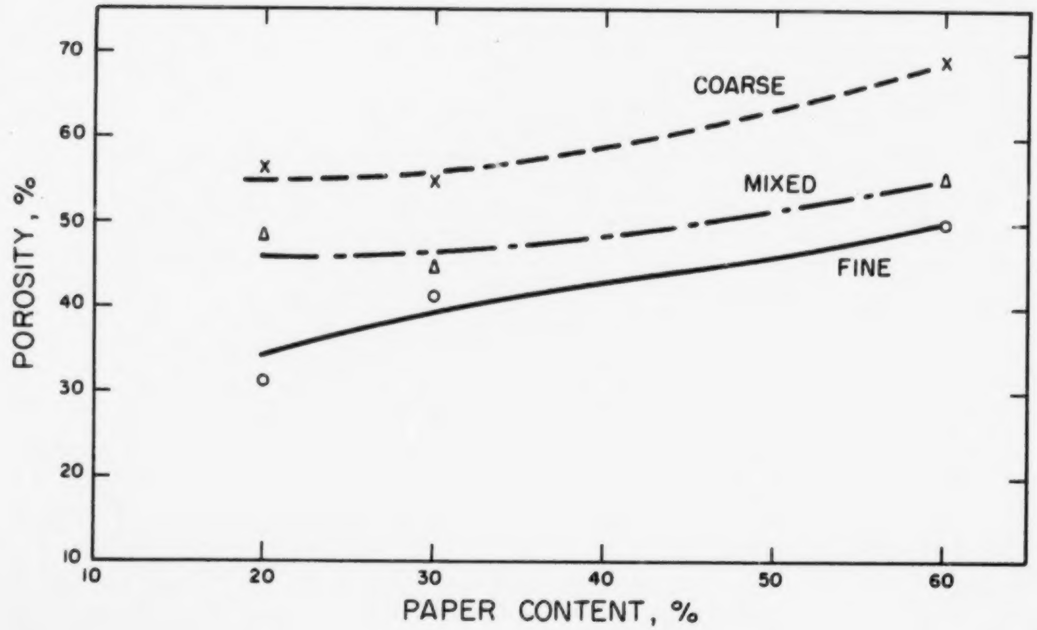
EFFECT OF COMPOSITION AND SIZE ON COMPACTED UNIT WEIGHT UNWETTED REFUSE MIXTURES*



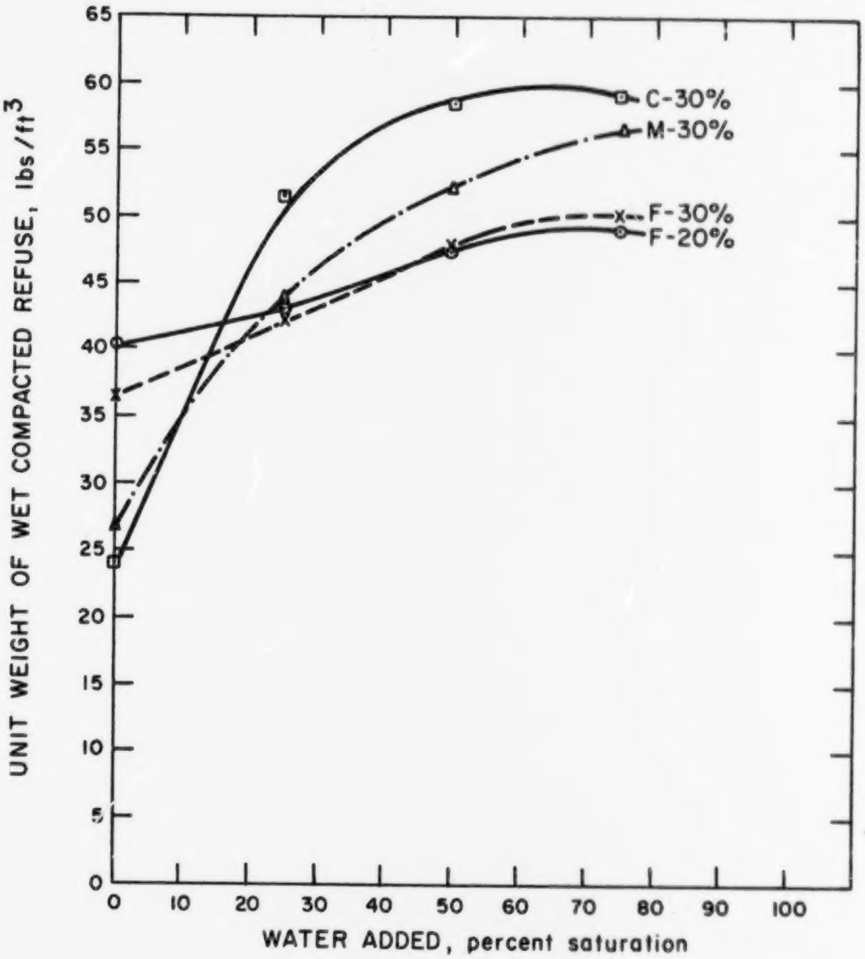
*See Table II-12 for Percent Water in Refuse

FIGURE II-11

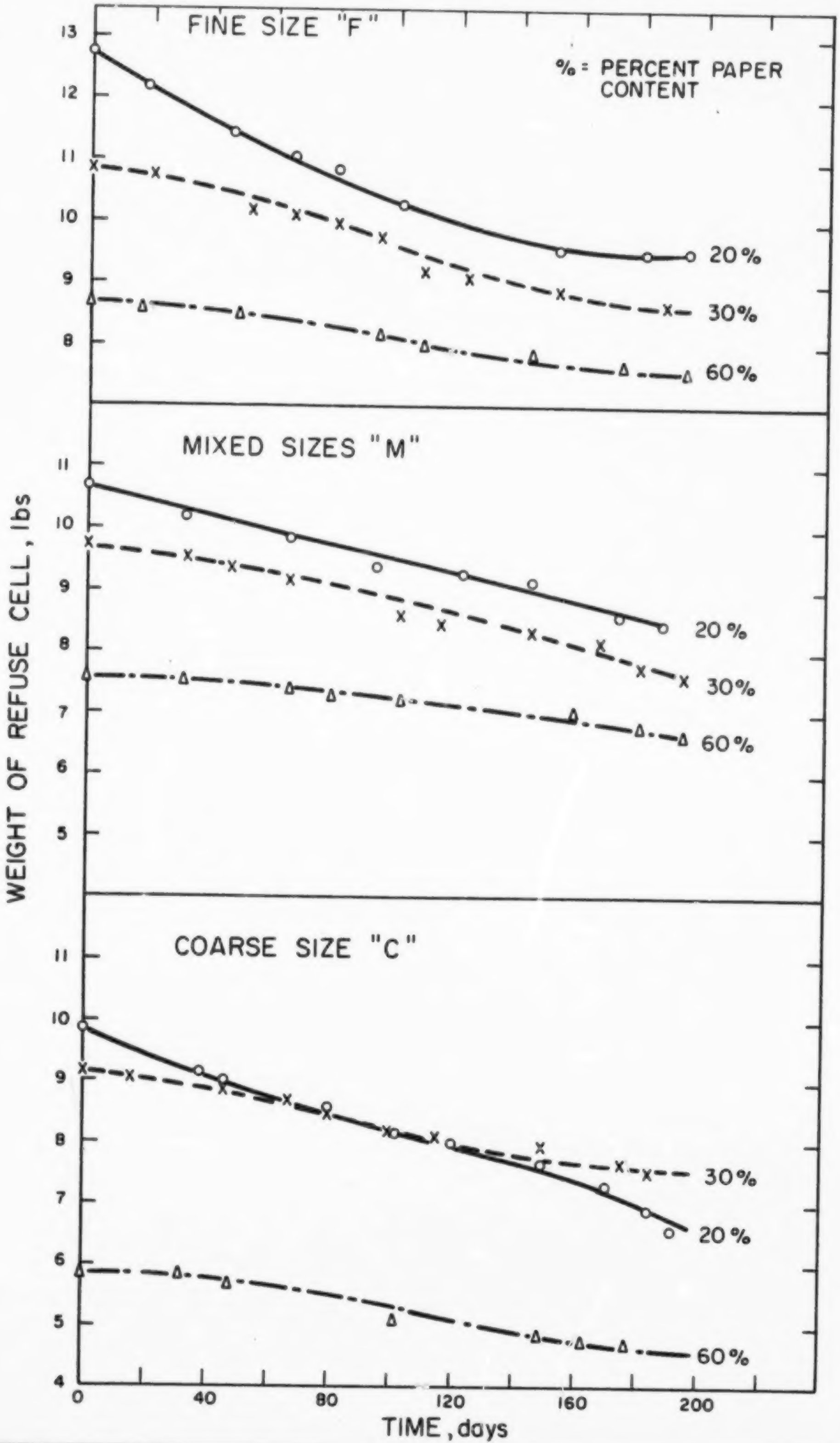
EFFECT OF COMPOSITION AND SIZE ON POROSITY OF COMPACTED REFUSE



EFFECT OF WATER ADDED ON UNIT WEIGHT OF COMPACTED REFUSE



WEIGHT LOSS DURING DECOMPOSITION AND SUBSIDENCE: AEROBIC, DRY REFUSE CELLS



WEIGHT LOSS DURING DECOMPOSITION AND SUBSIDENCE: ANAEROBIC, DRY REFUSE CELLS

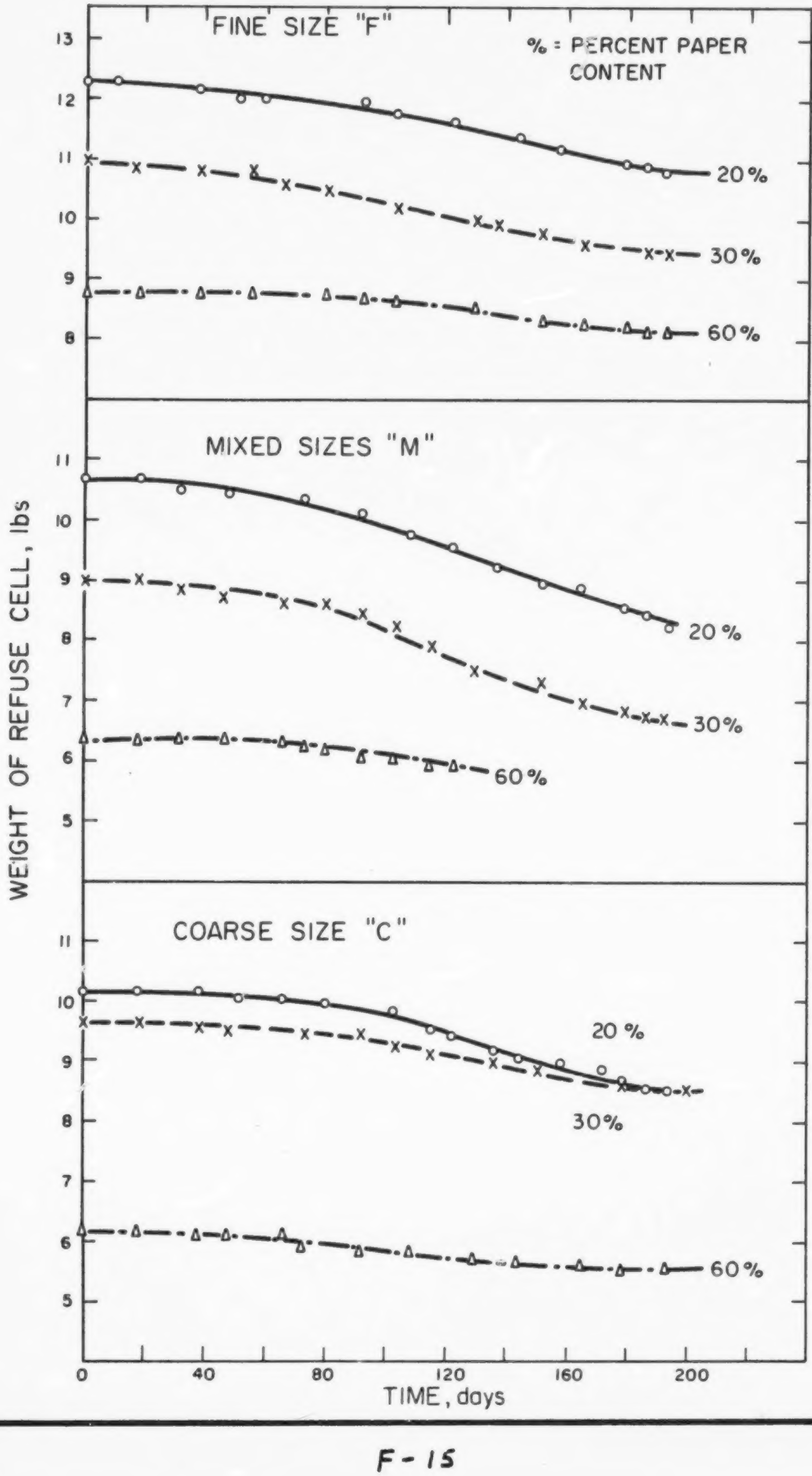


FIGURE II-15

WEIGHT LOSS DURING DECOMPOSITION AND SUBSIDENCE:
AEROBIC, 65% SATURATED REFUSE CELLS

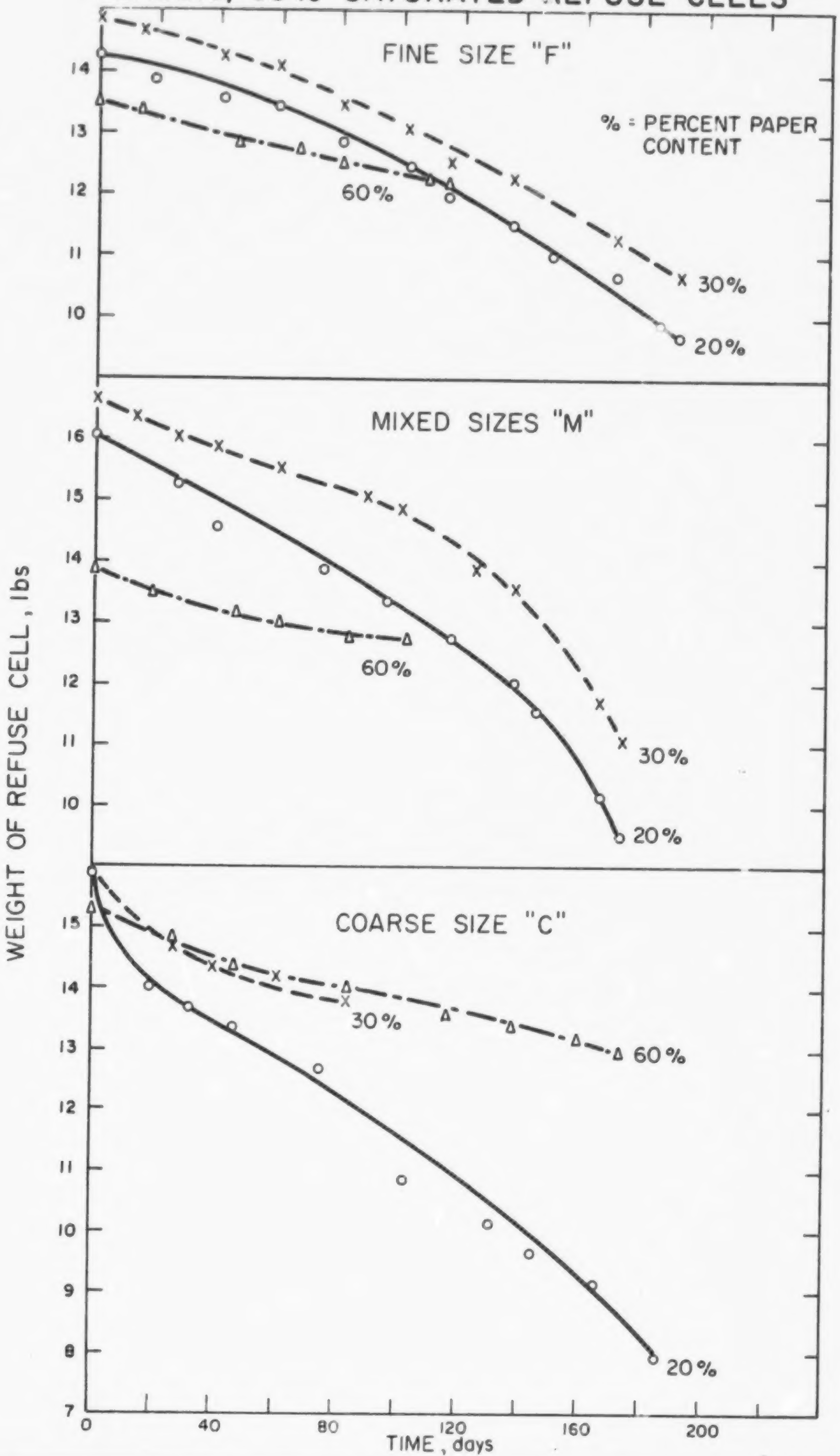


FIGURE II-16

WEIGHT LOSS DURING DECOMPOSITION AND SUBSIDENCE: ANAEROBIC, 65% SATURATED REFUSE CELLS

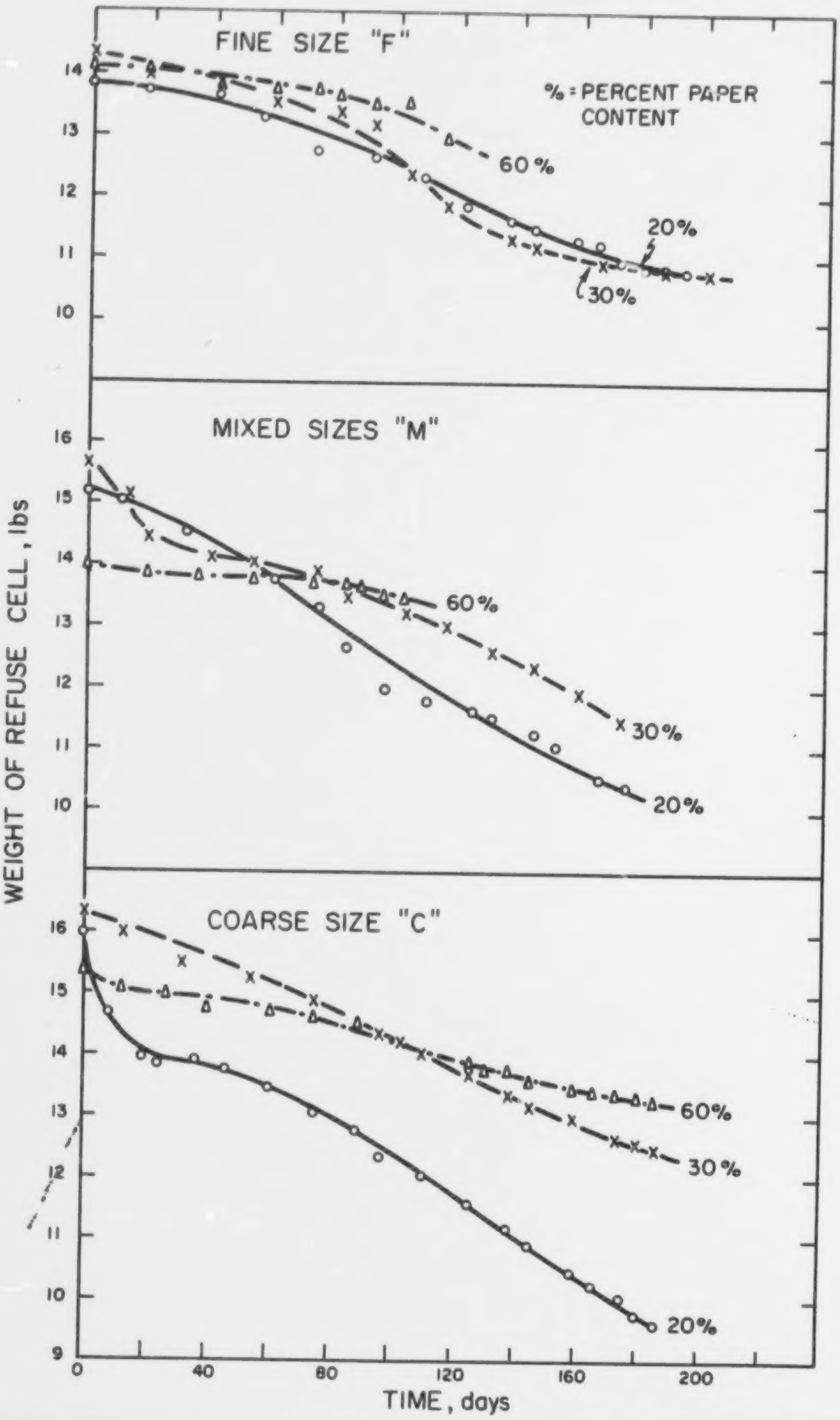


FIGURE II-17

WEIGHT LOSS DURING DECOMPOSITION AND SUBSIDENCE: ANAEROBIC, SATURATED REFUSE CELLS

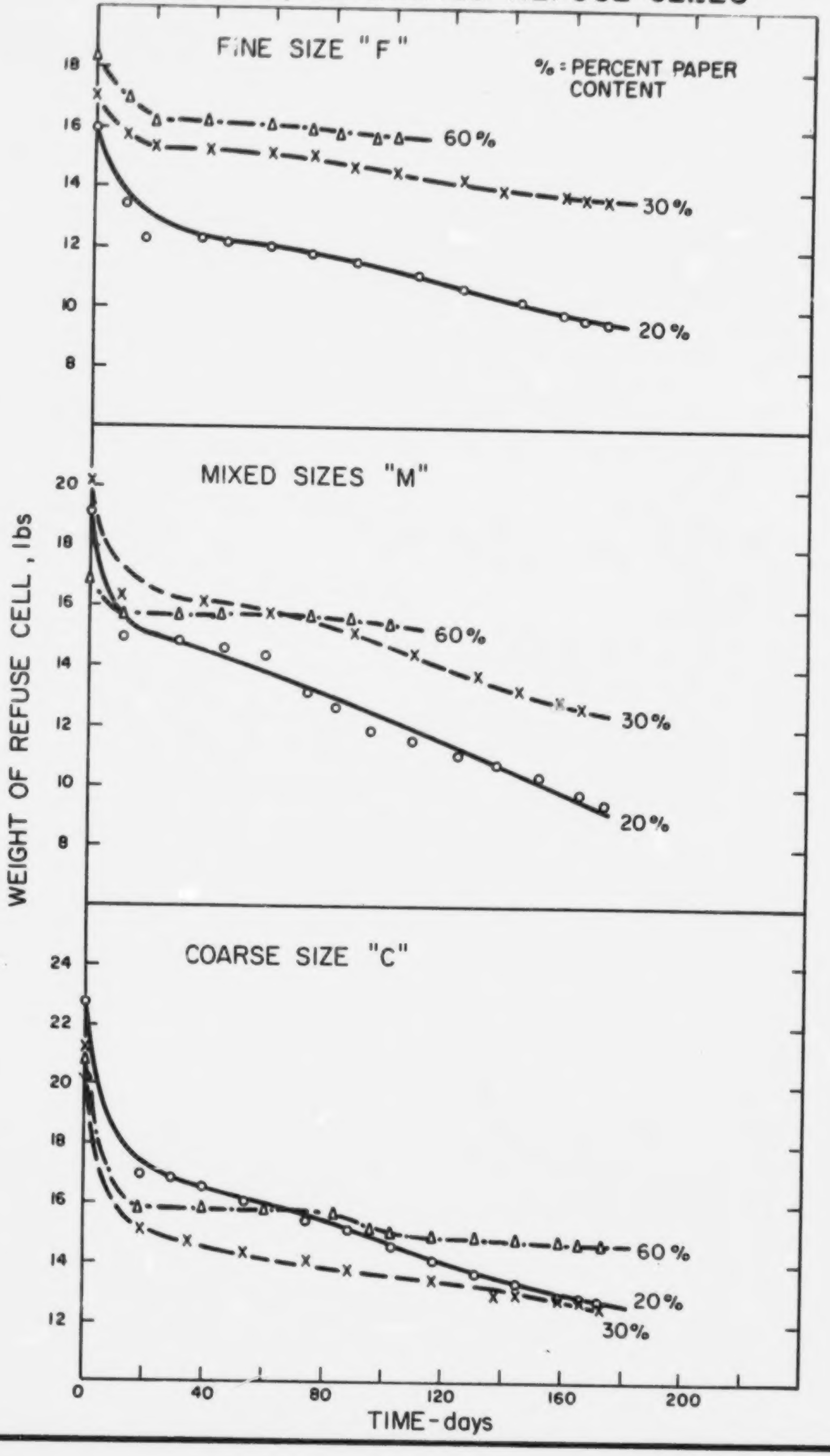
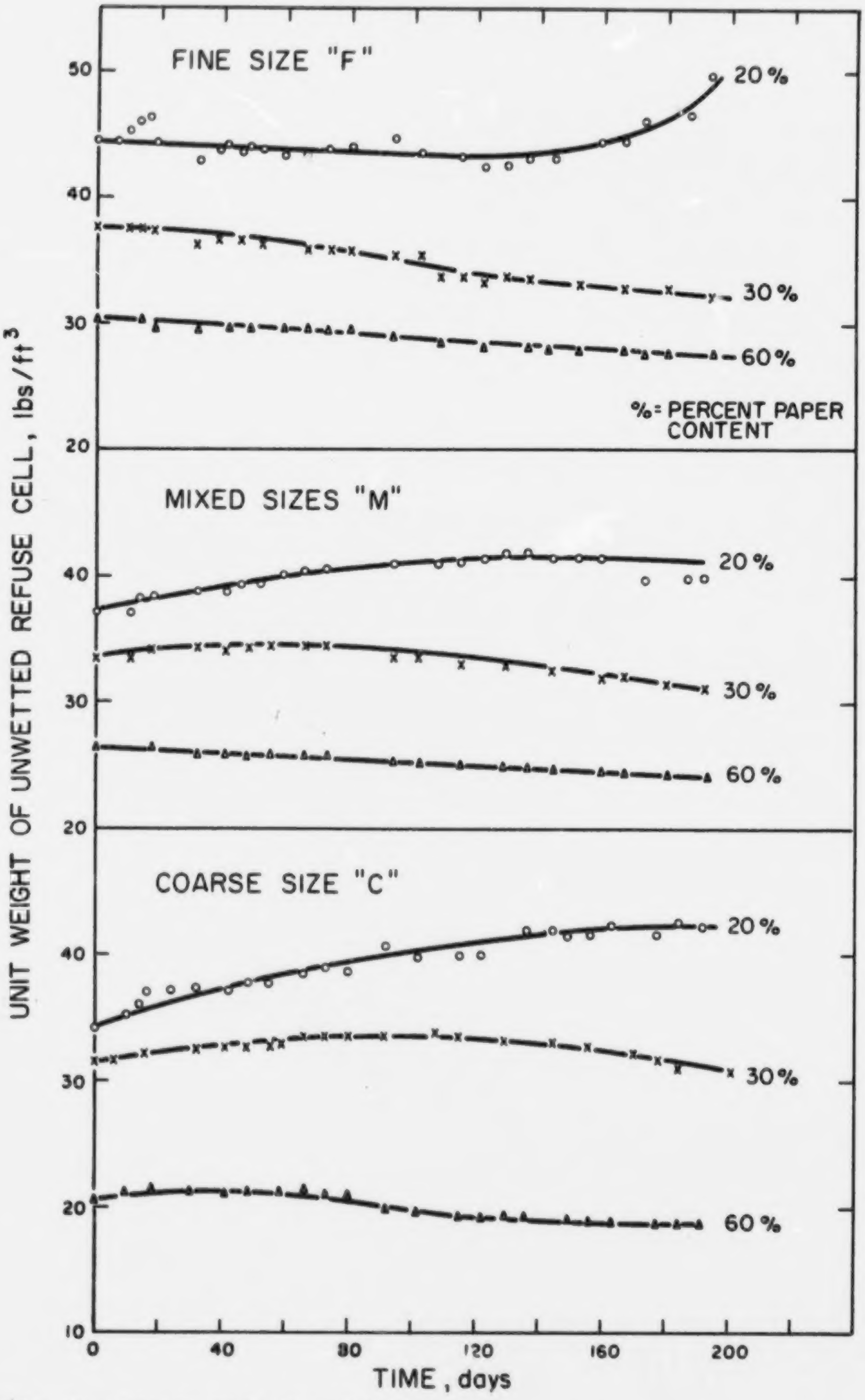


FIGURE II-18

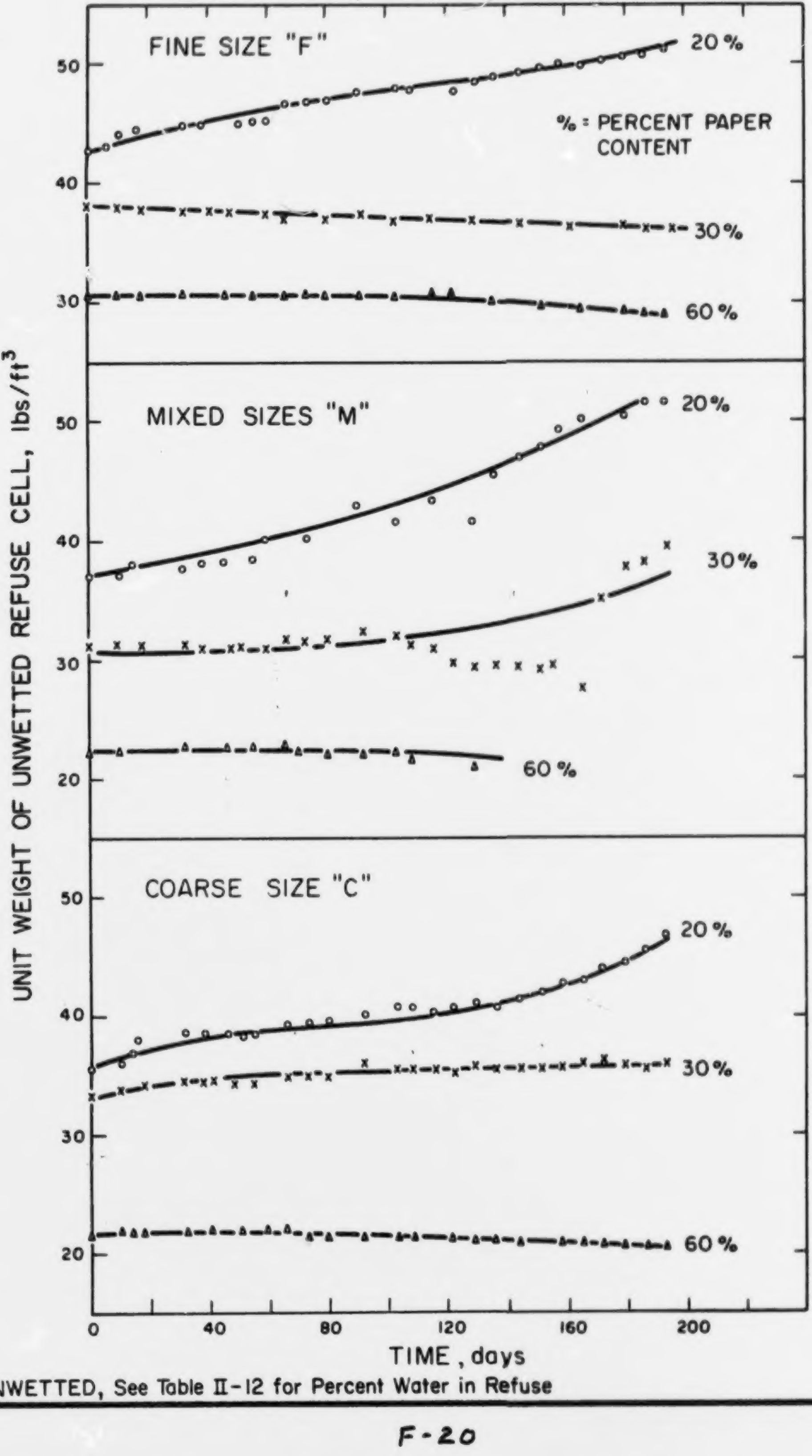
UNIT WEIGHT DURING DECOMPOSITION AND SUBSIDENCE: AEROBIC, DRY* REFUSE CELLS



*UNWETTED, See Table II-12 for Percent Water in Refuse

FIGURE II-19

UNIT WEIGHT DURING DECOMPOSITION AND SUBSIDENCE: ANAEROBIC, DRY* REFUSE CELLS



*UNWETTED, See Table II-12 for Percent Water in Refuse

FIGURE II-20

UNIT WEIGHT DURING DECOMPOSITION AND SUBSIDENCE: AEROBIC, 65% SATURATED REFUSE CELLS

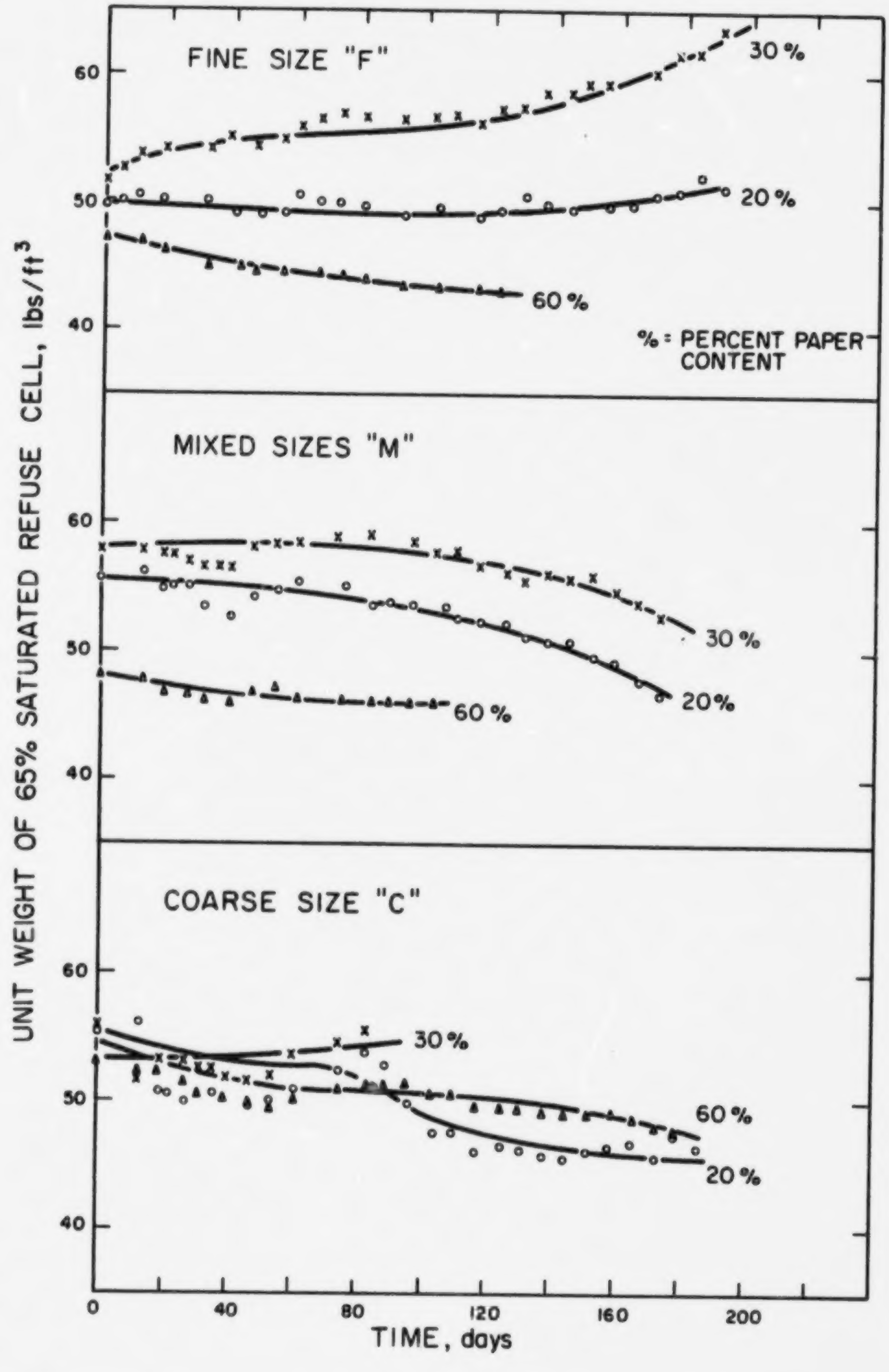


FIGURE II-21

UNIT WEIGHT DURING DECOMPOSITION AND SUBSIDENCE: ANAEROBIC, 65% SATURATED REFUSE CELLS

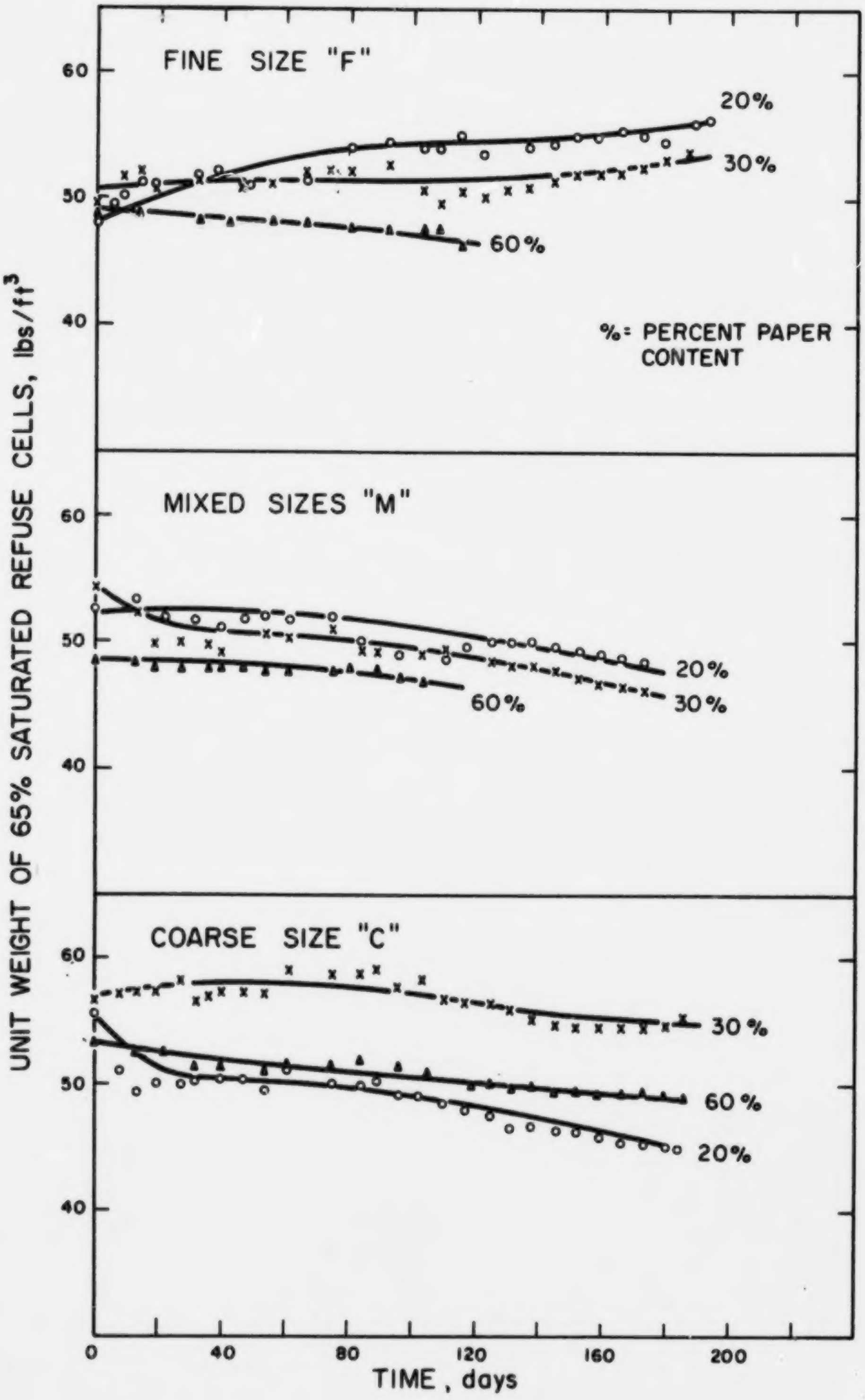


FIGURE II-22

UNIT WEIGHT DURING DECOMPOSITION AND SUBSIDENCE: ANAEROBIC, SATURATED REFUSE CELLS

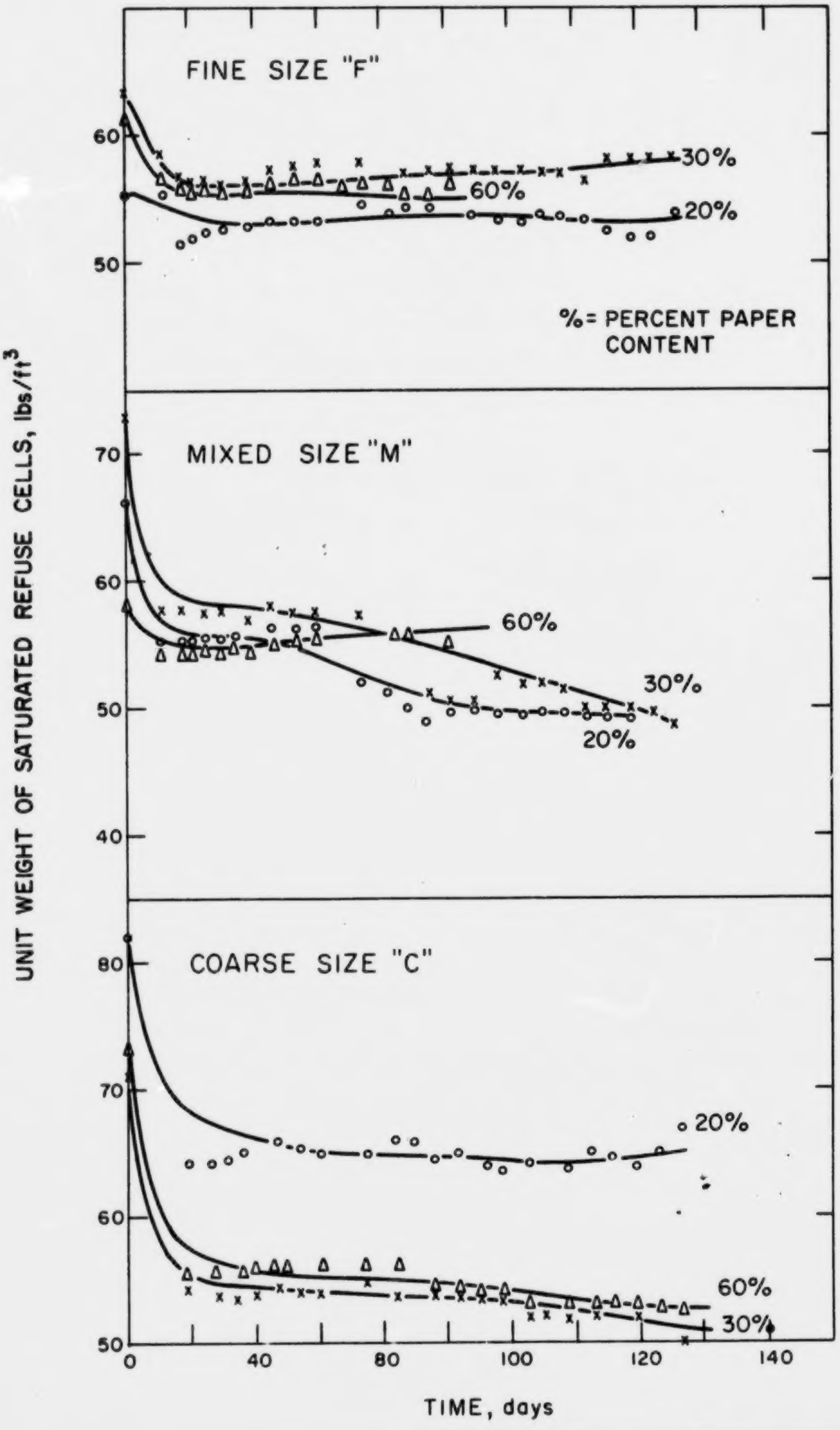
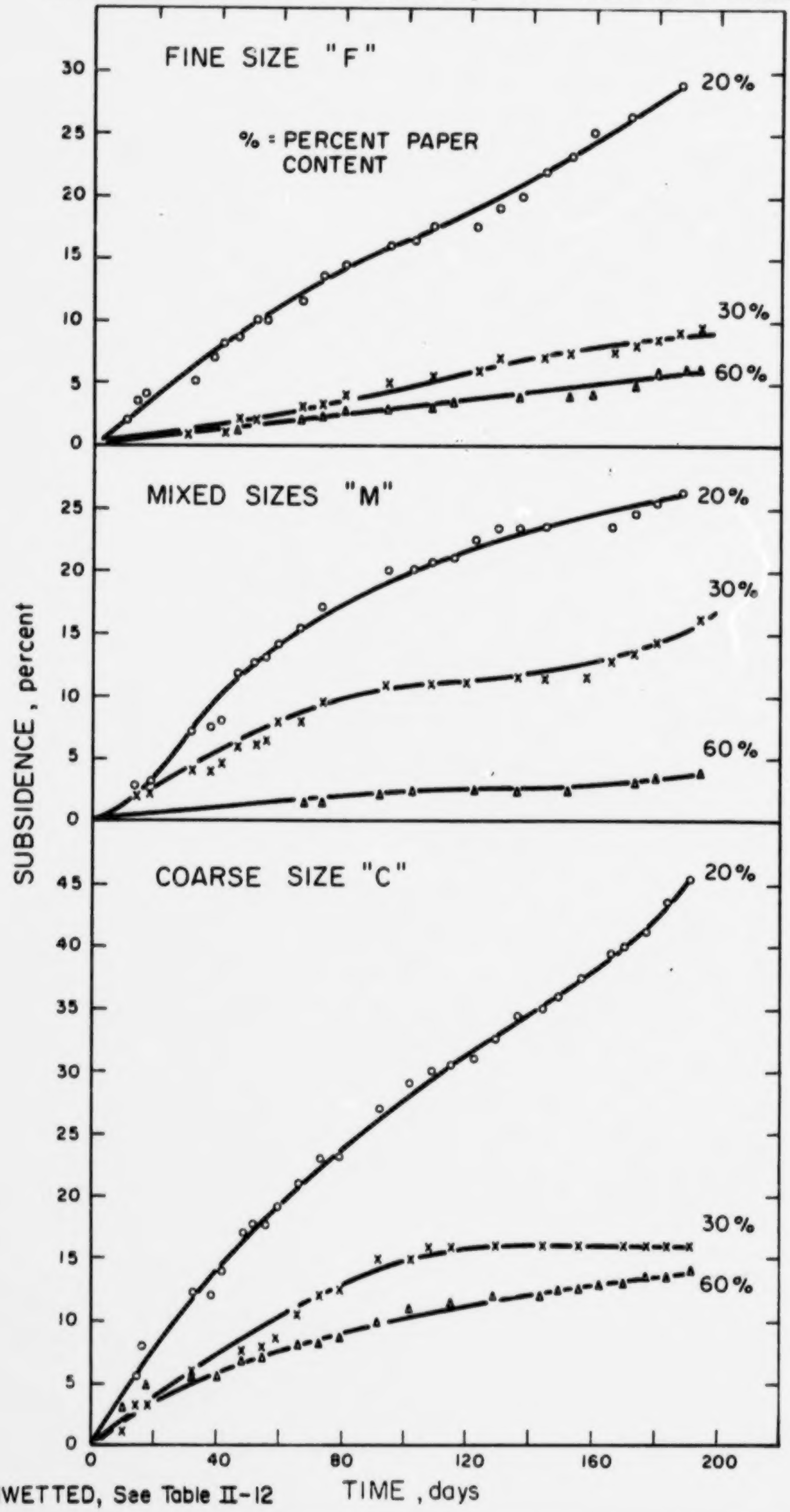


FIGURE II-23

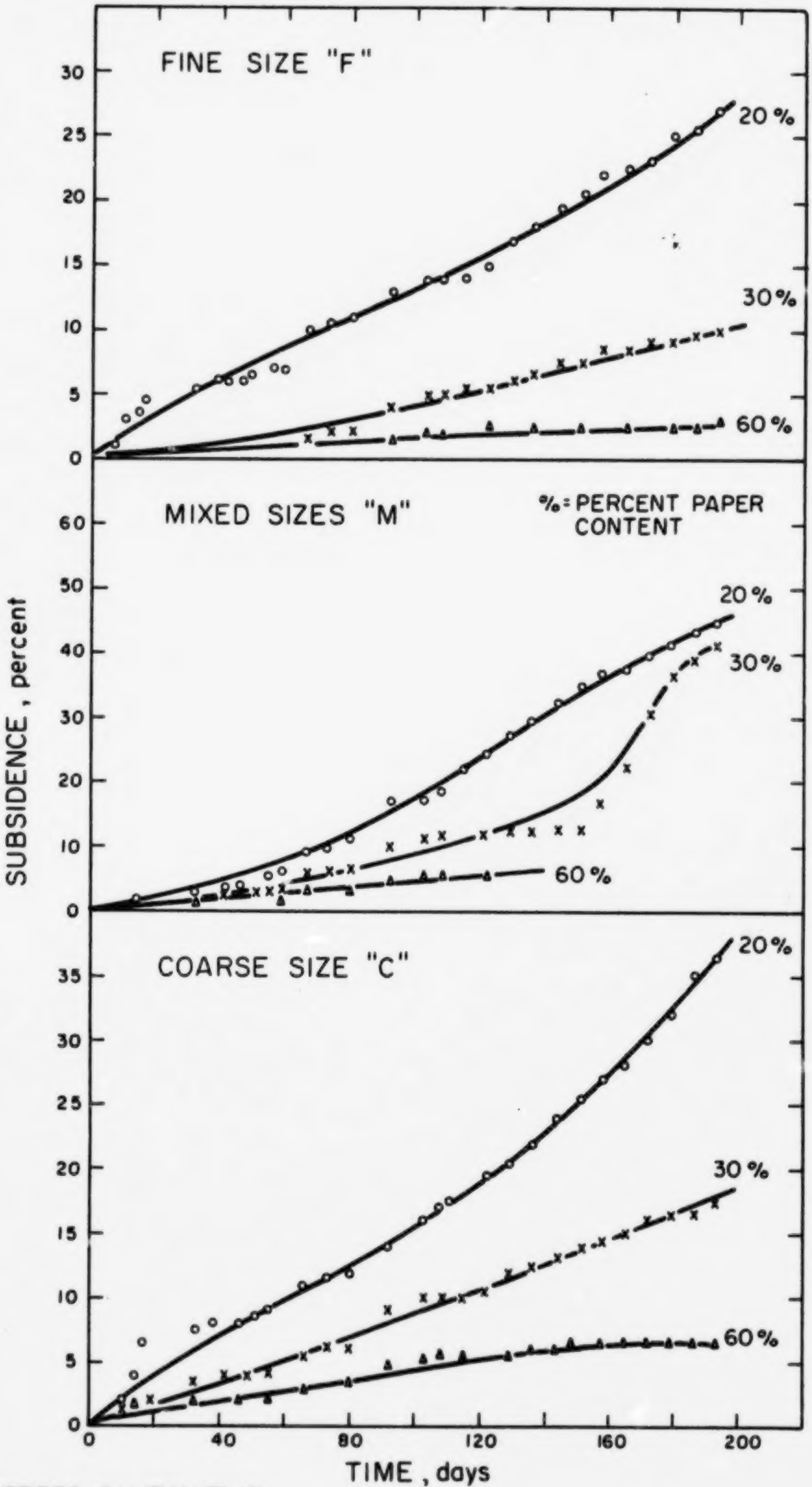
SUBSIDENCE OF AEROBIC, DRY* REFUSE CELLS



*UNWETTED, See Table II-12

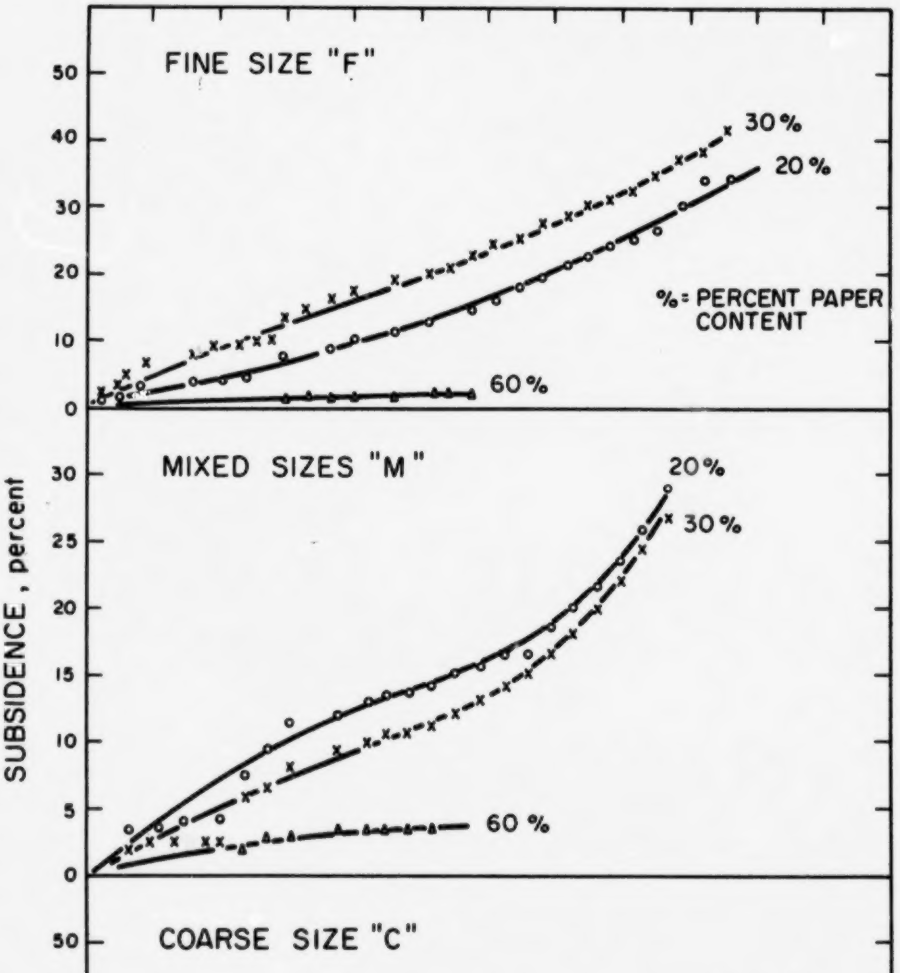
FIGURE II-24

SUBSIDENCE OF ANAEROBIC, DRY* REFUSE CELLS



*UNWETTED, See Table II-12

SUBSIDENCE OF AEROBIC, 65% SATURATED REFUSE CELLS



SUBSIDENCE OF ANAEROBIC, 65% SATURATED REFUSE CELLS

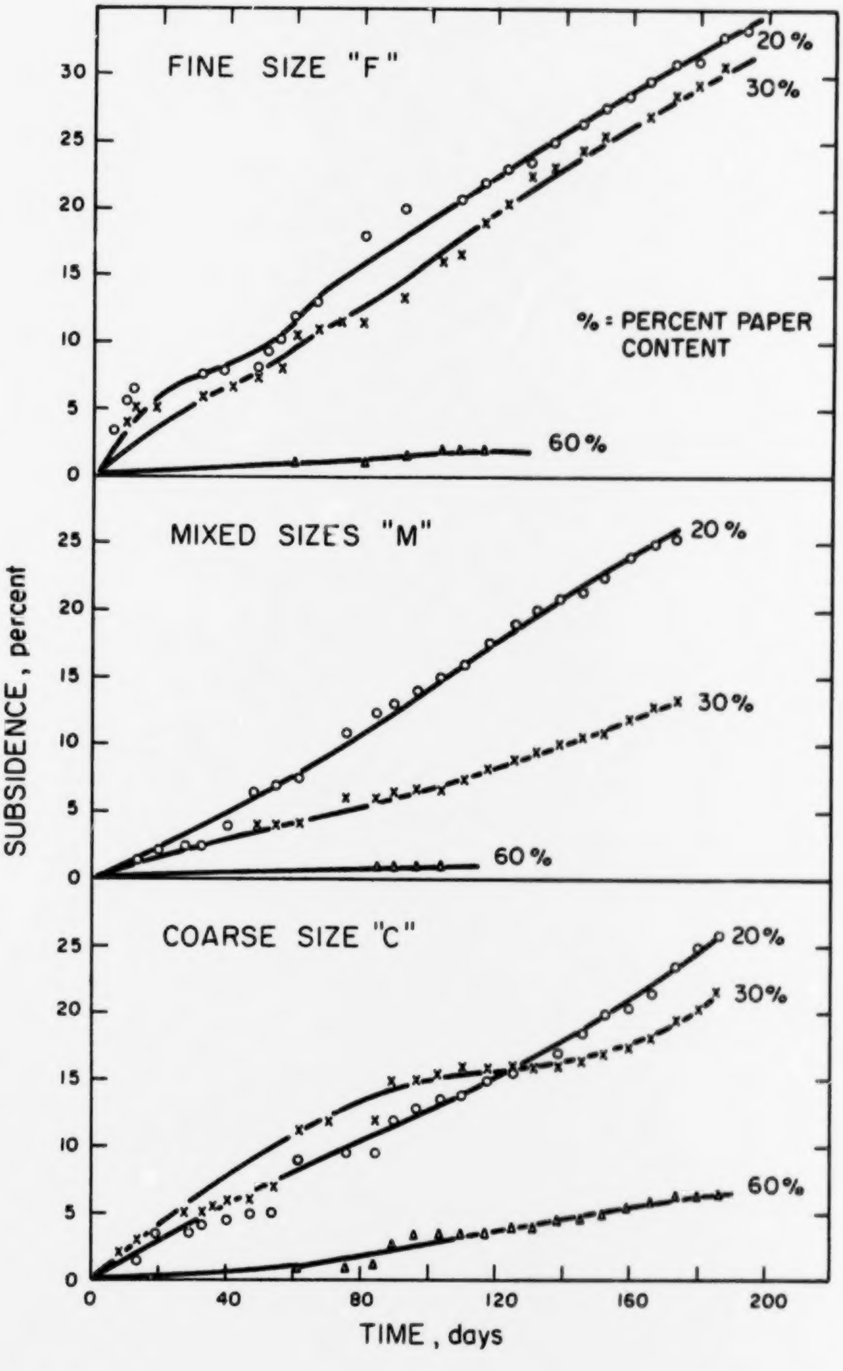
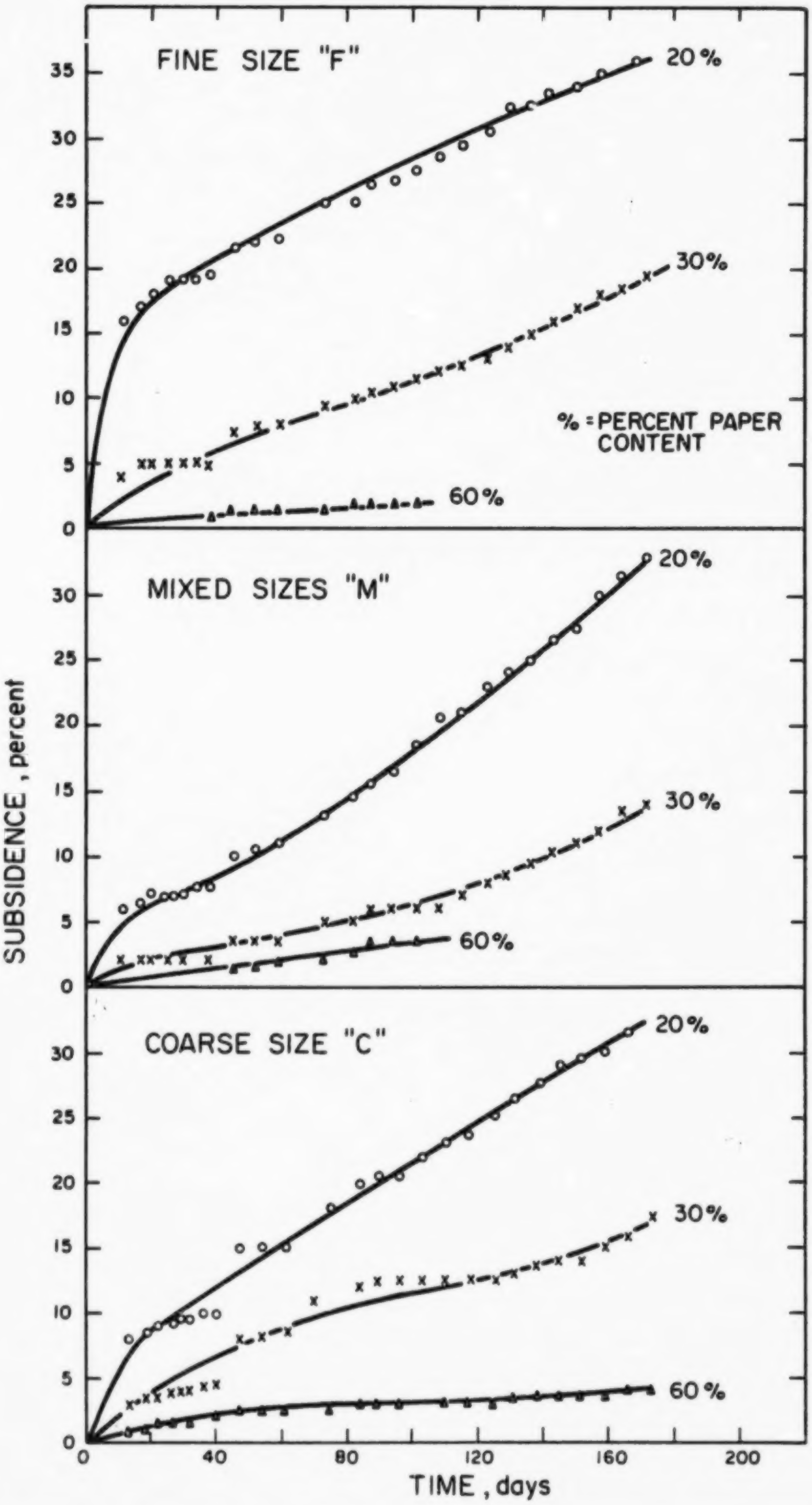


FIGURE II-27

SUBSIDENCE OF ANAEROBIC, SATURATED REFUSE CELLS



AVERAGE ANNUAL SUBSIDENCE RATES AT 180 DAYS
SIZE OF REFUSE : FINE

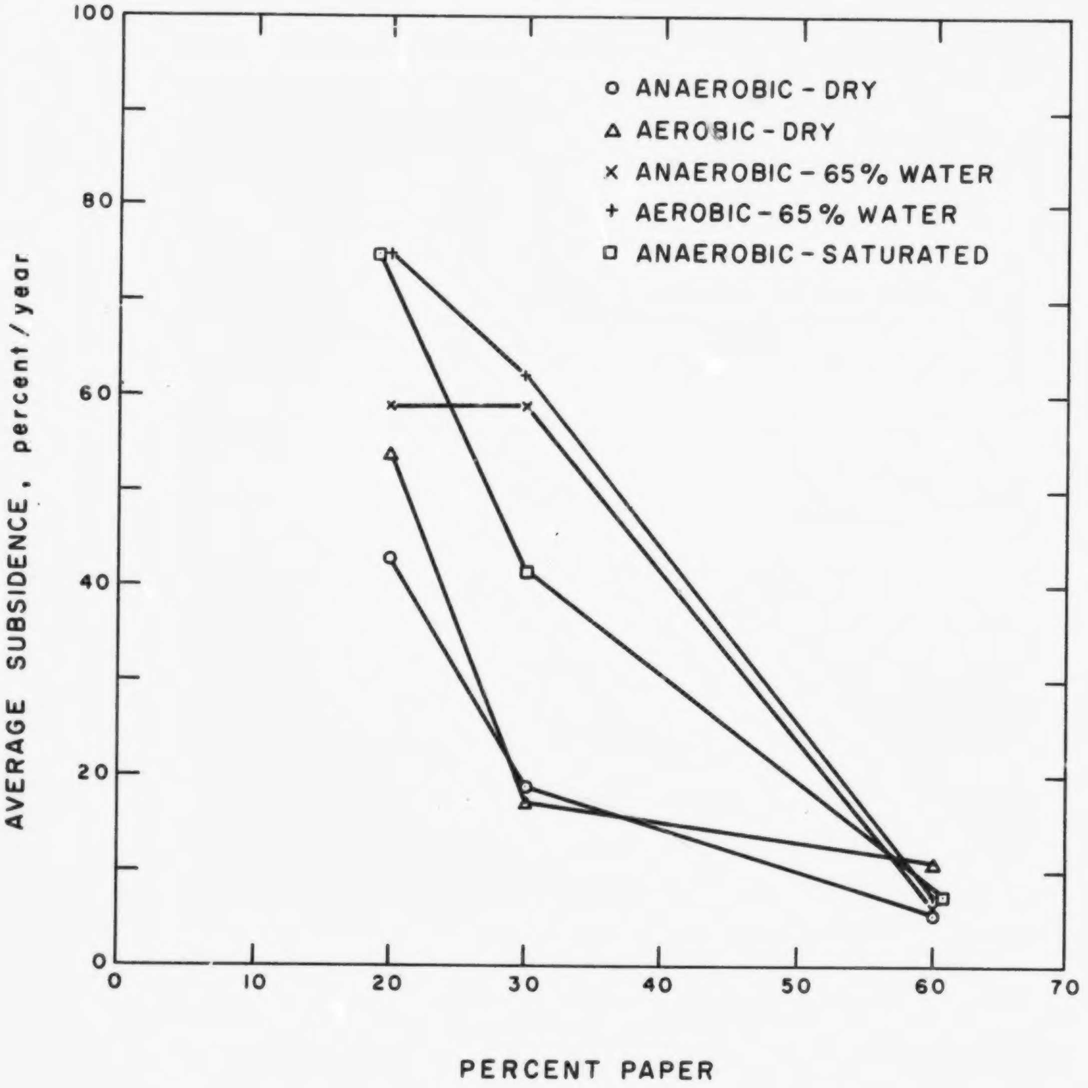


FIGURE II-29

AVERAGE ANNUAL SUBSIDENCE
RATES AT 180 DAYS
SIZE OF REFUSE: MIXED

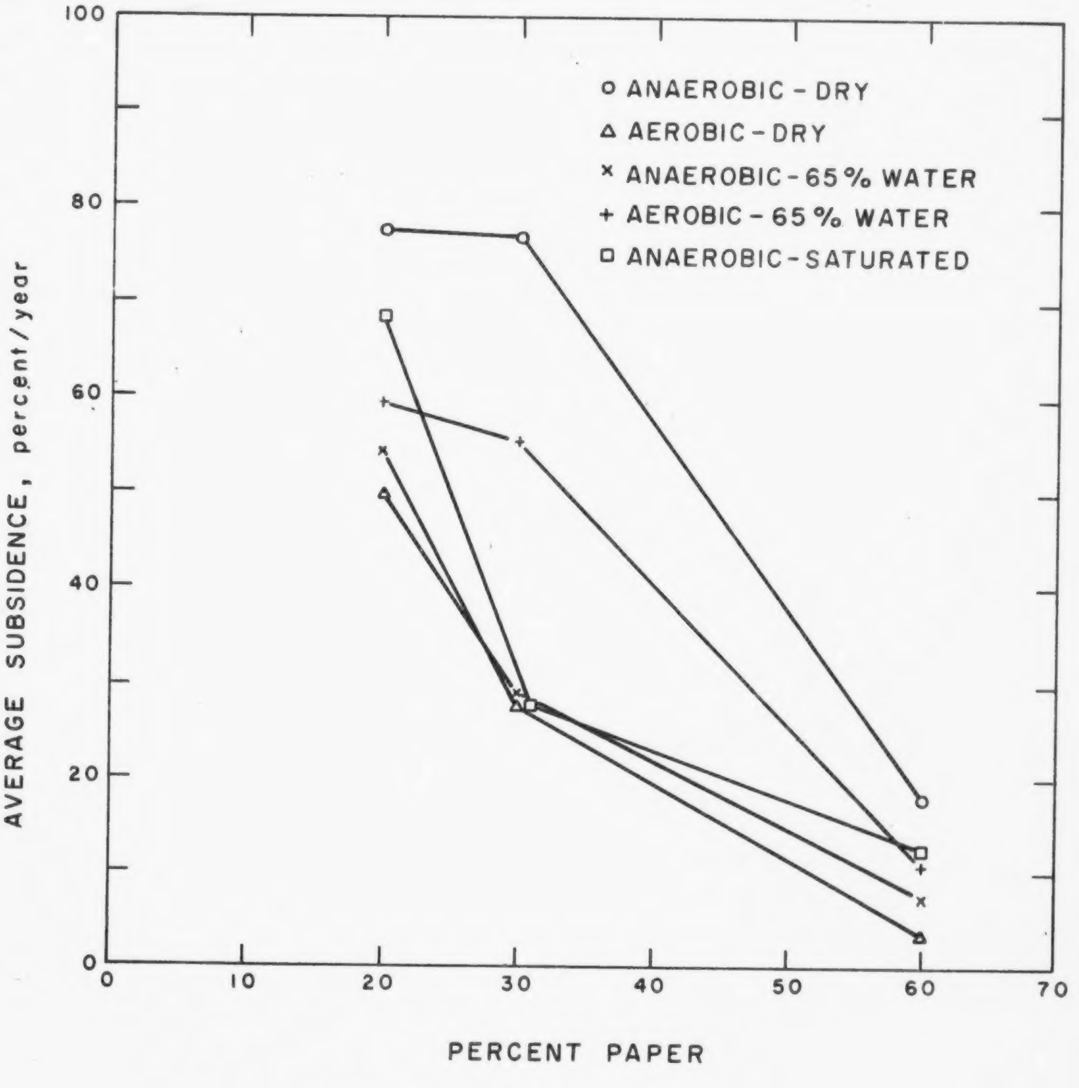


FIGURE II-30

AVERAGE ANNUAL SUBSIDENCE
RATES AT 180 DAYS
SIZE OF REFUSE: COARSE

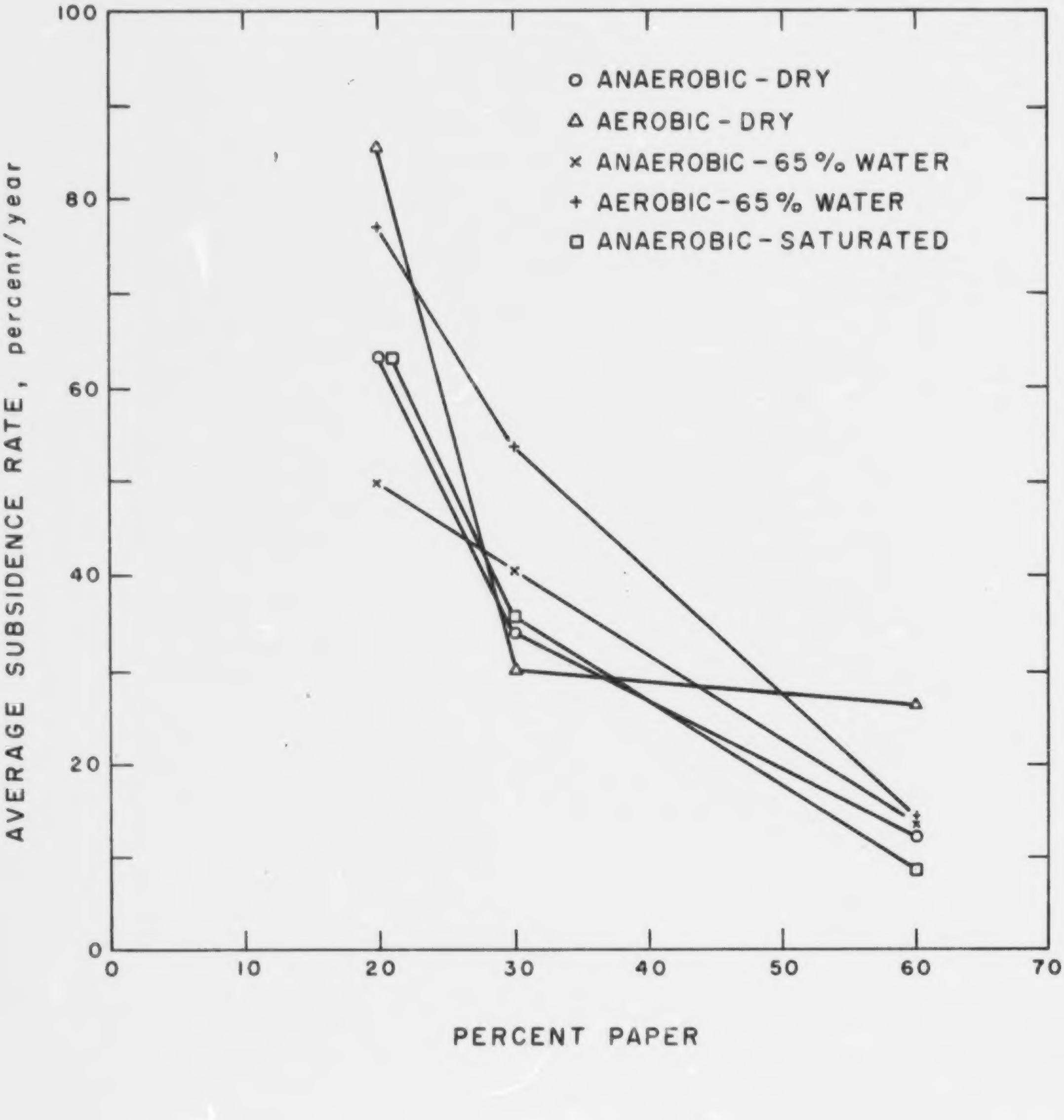
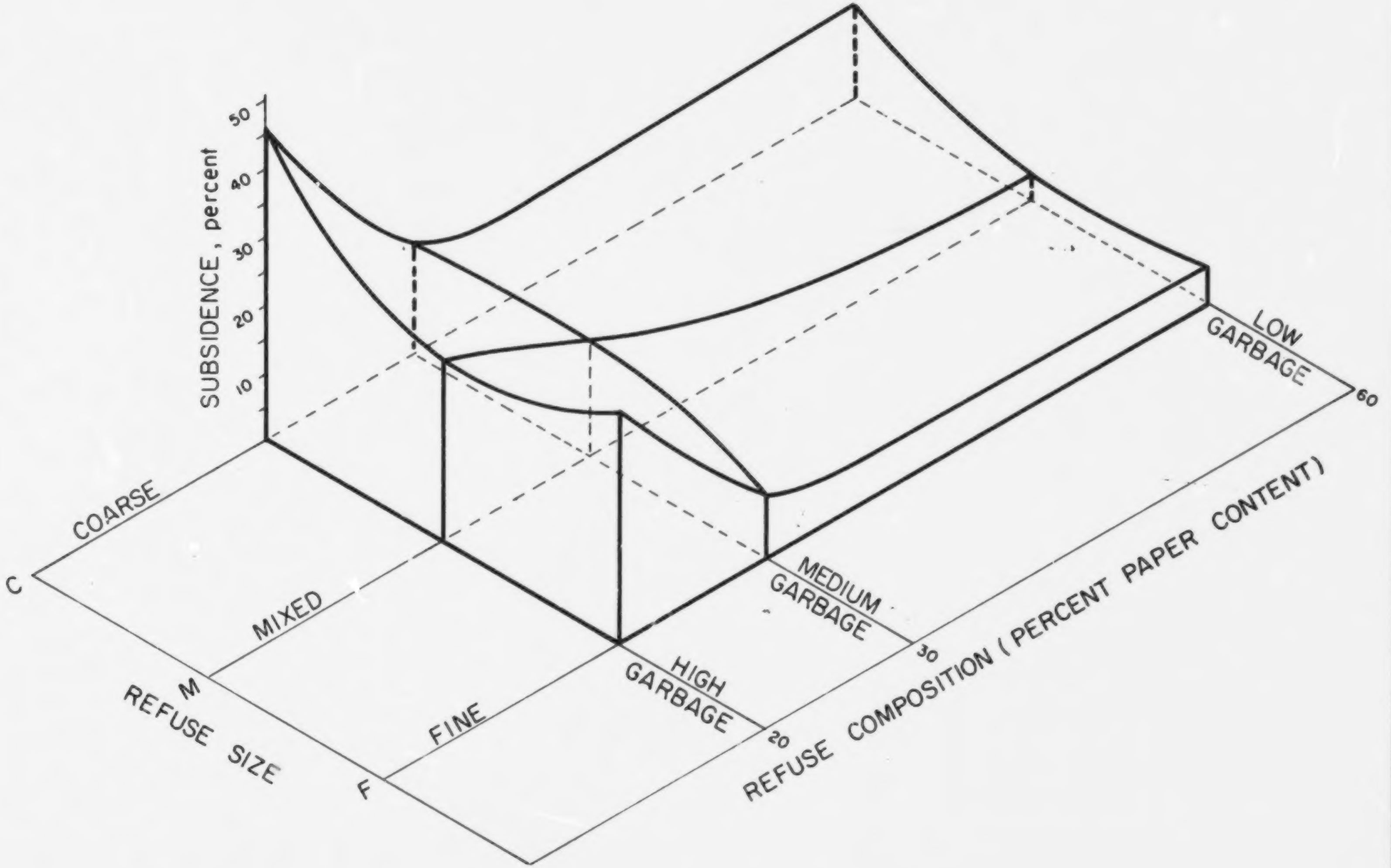
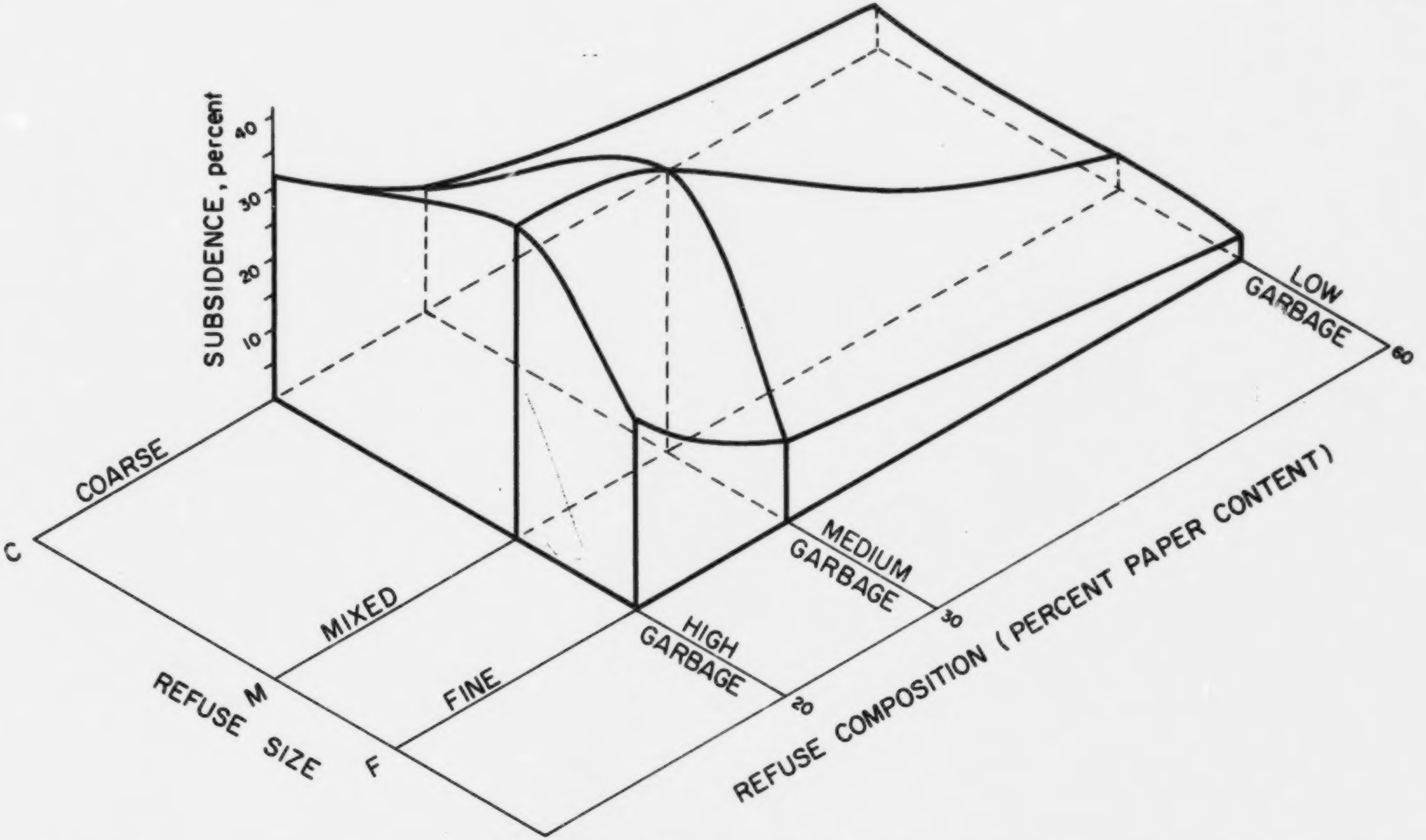


FIGURE II-31



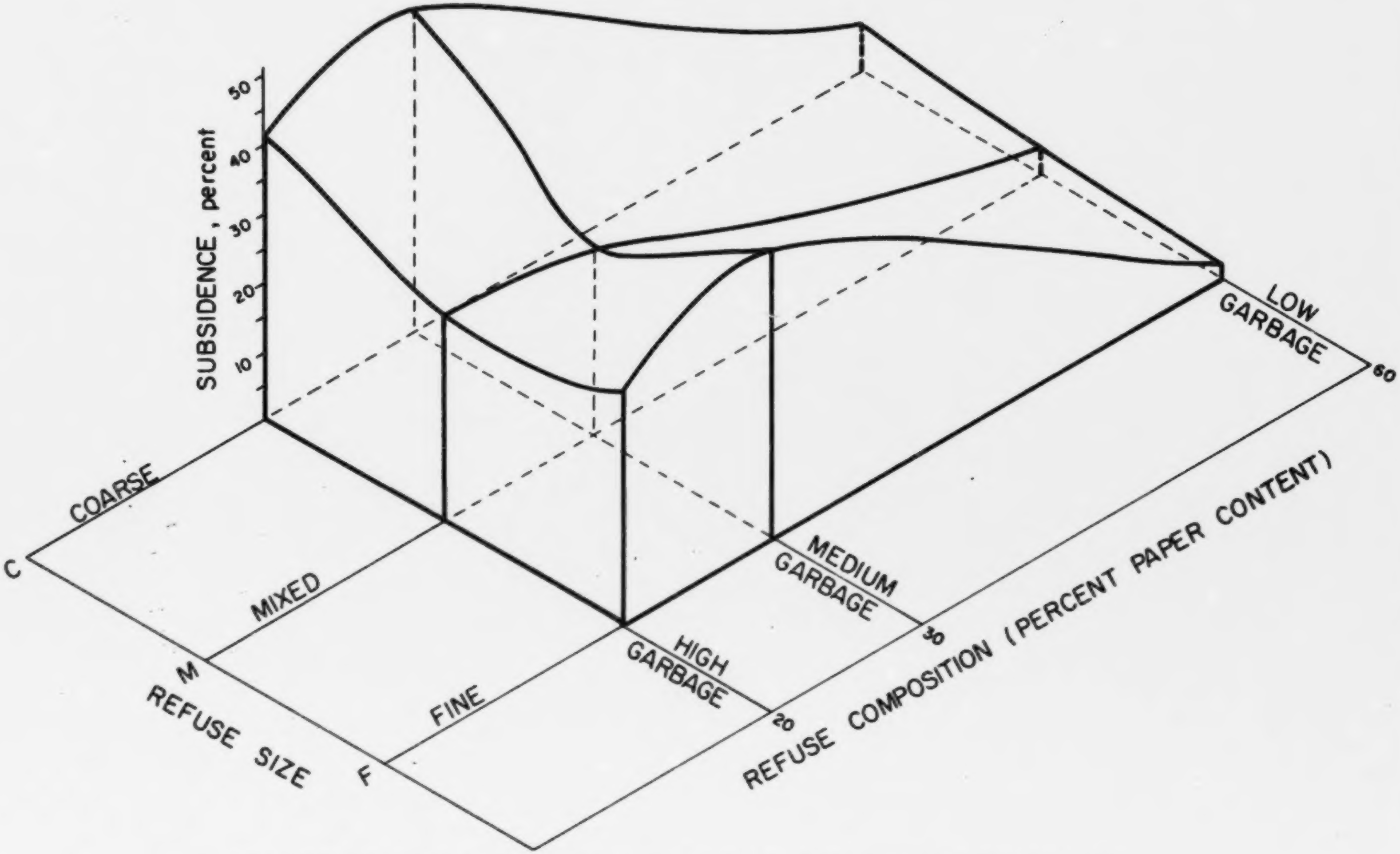
ULTIMATE SUBSIDENCE (END OF 200 DAY TEST PERIOD) OF AEROBIC, DRY REFUSE CELLS

FIGURE II-32



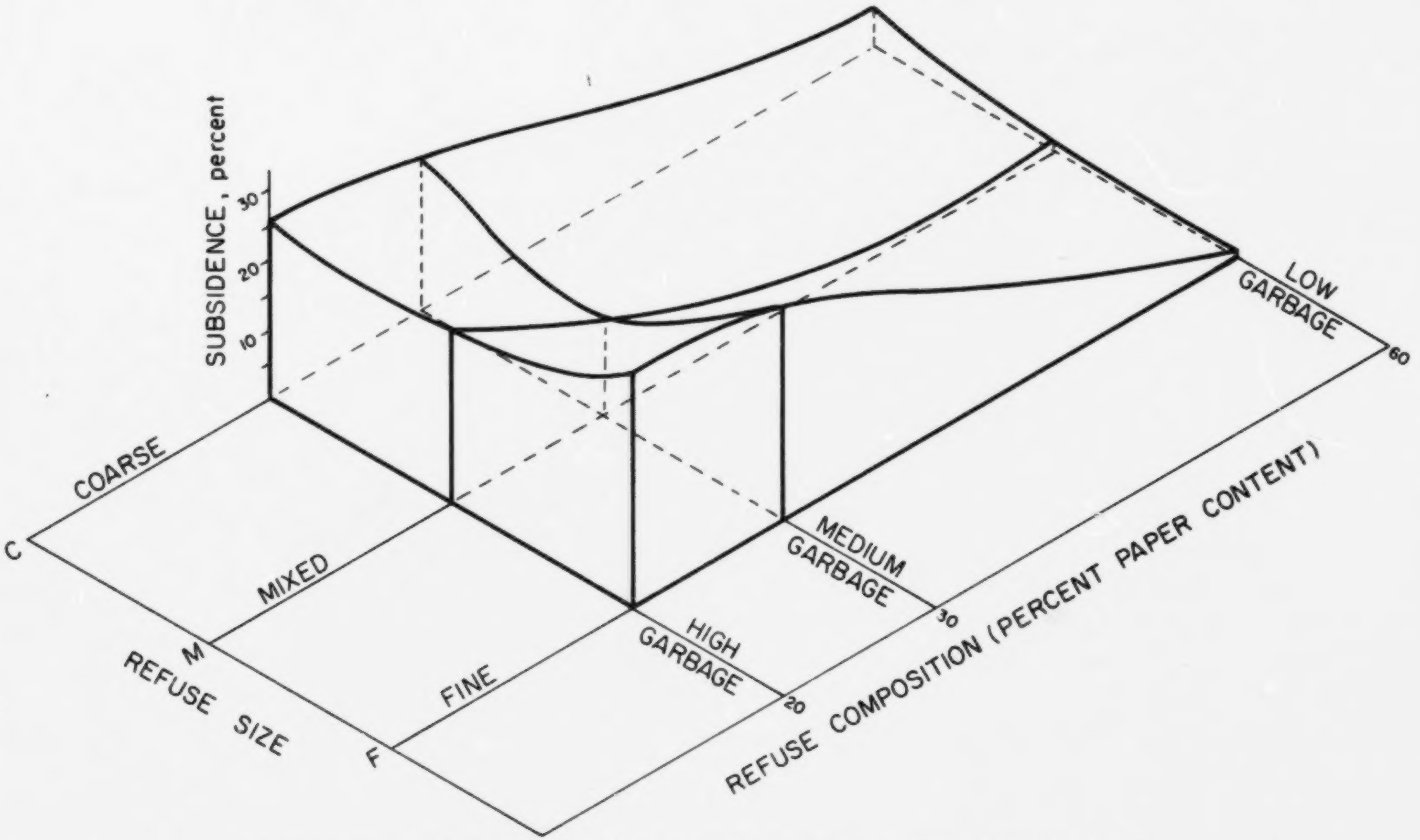
ULTIMATE SUBSIDENCE (END OF 200 DAY TEST PERIOD) OF ANAEROBIC, DRY REFUSE CELLS

FIGURE II-33

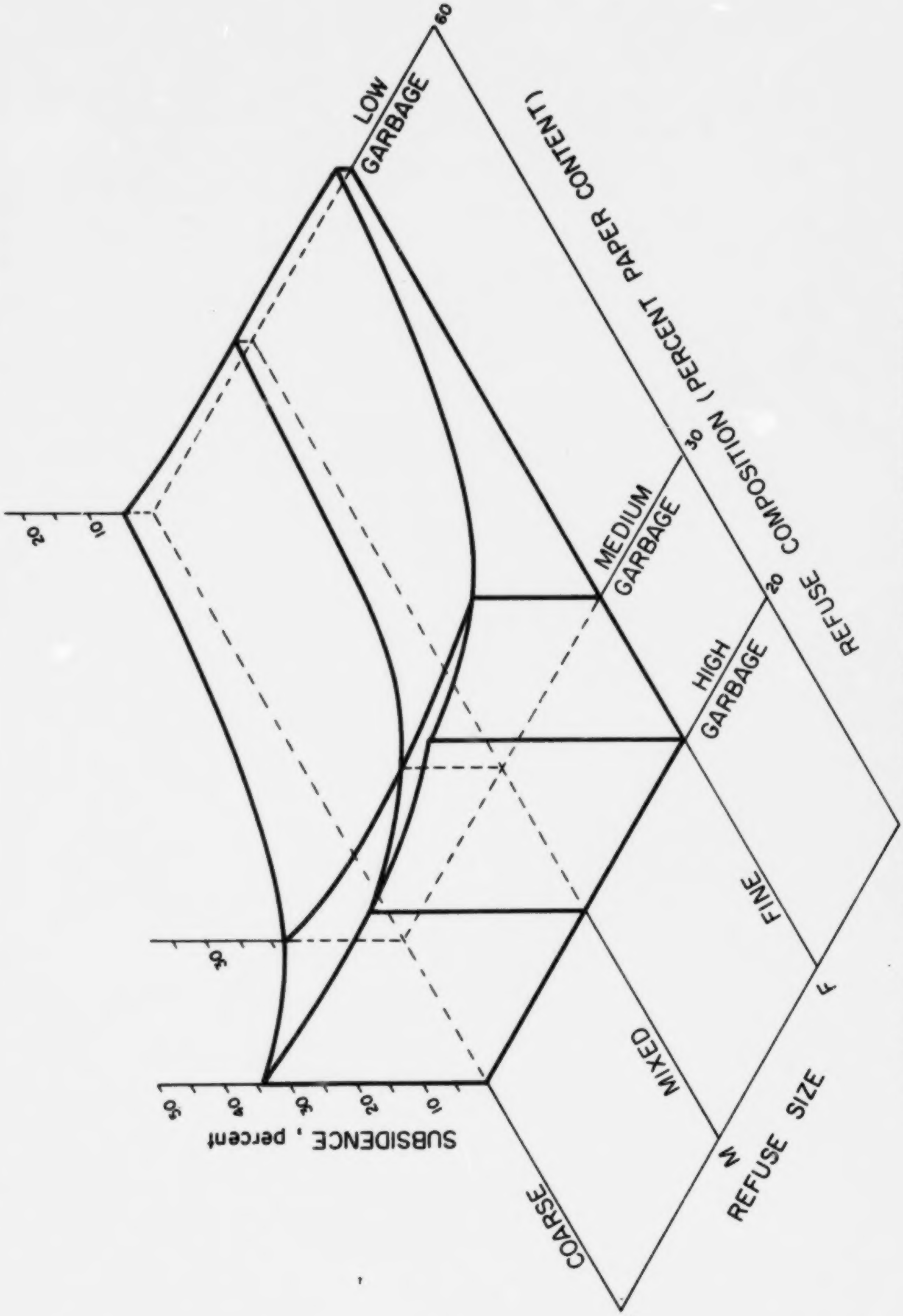


ULTIMATE SUBSIDENCE (END OF 200 DAY TEST PERIOD) OF AEROBIC, 65% SATURATED REFUSE CELLS

FIGURE II-34



ULTIMATE SUBSIDENCE (END OF 200 DAY TEST PERIOD) OF ANAEROBIC, 65% SATURATED REFUSE CELLS



ULTIMATE SUBSIDENCE (END OF 200 DAY TEST PERIOD) OF ANAEROBIC, SATURATED REFUSE CELLS

FIGURE II-36

CONSOLIDATION OF ANAEROBIC, SATURATED REFUSE CELL,
30 PERCENT PAPER, COARSE SIZE MATERIALS

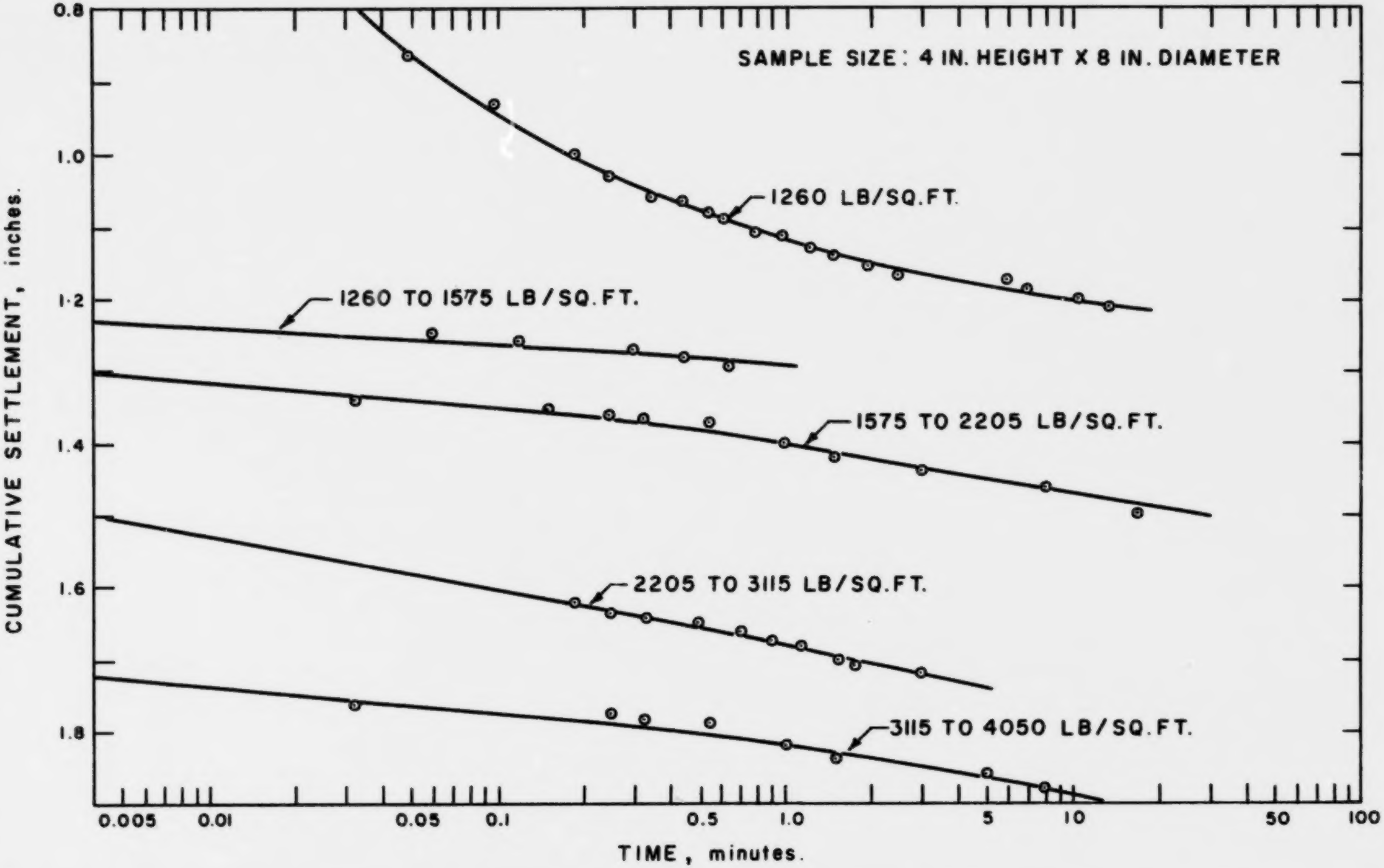


FIGURE II-37

CONSOLIDATION OF ANAEROBIC REFUSE CELL,
20 PERCENT PAPER, COARSE SIZE MATERIALS, 25 PERCENT SATURATED

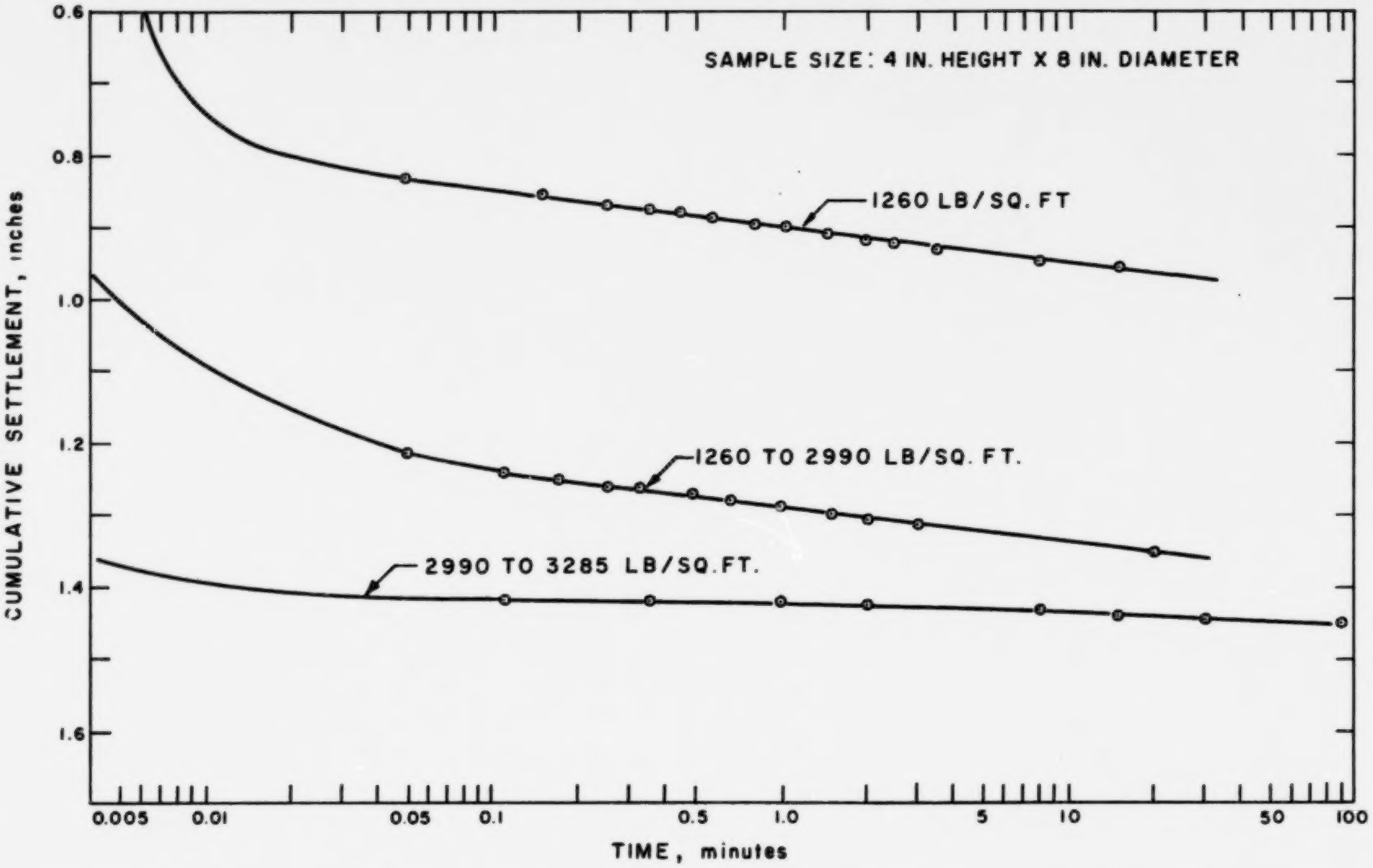


FIGURE II - 38

CONSOLIDATION OF AEROBIC REFUSE CELL, 60 PERCENT PAPER, COARSE SIZE MATERIALS, 15 PERCENT SATURATED

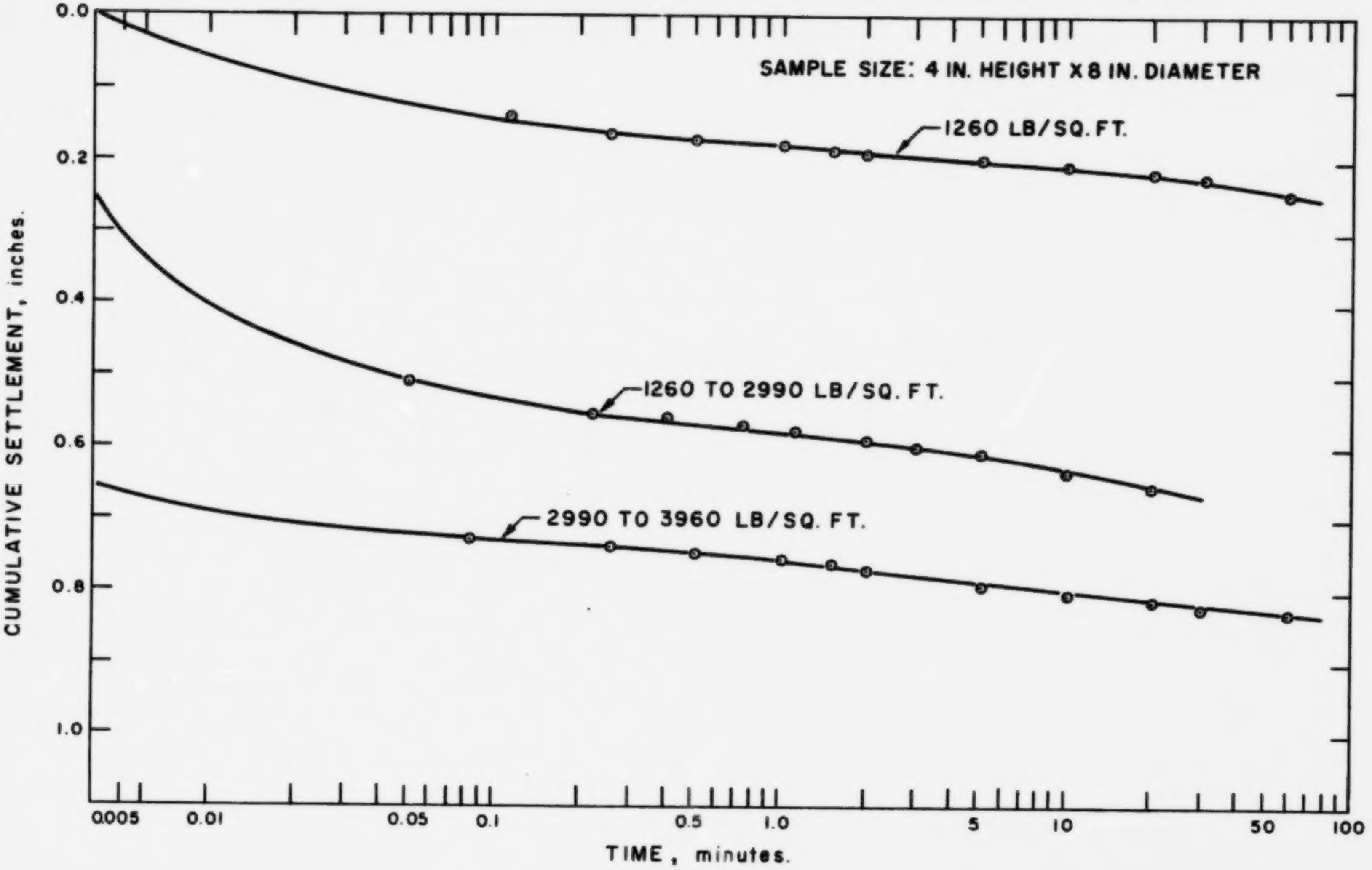


FIGURE II-39

STRESS – STRAIN CURVES: DRY AEROBIC REFUSE CELLS

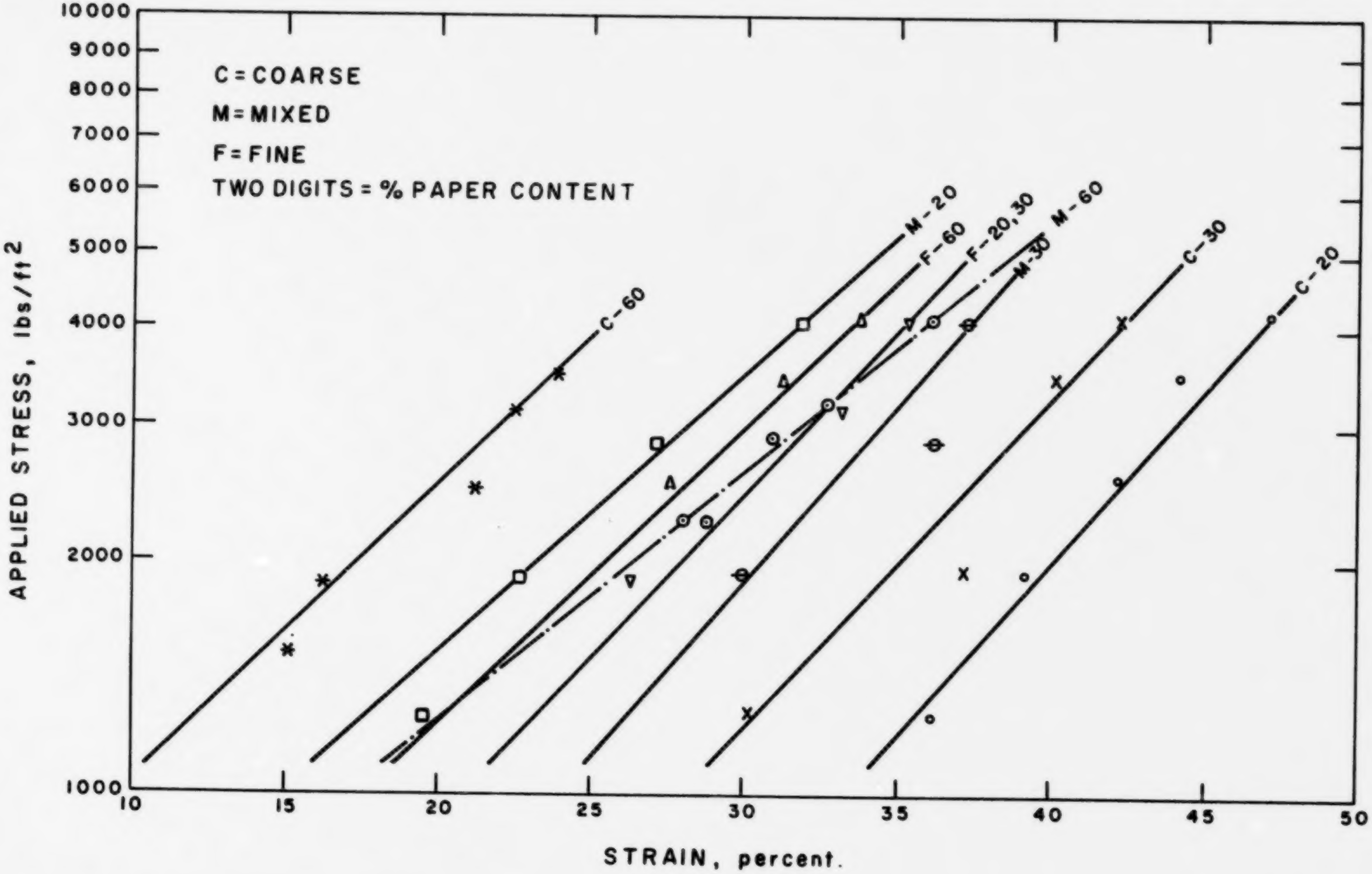


FIGURE II-40

STRESS - STRAIN CURVES: ANAEROBIC DRY REFUSE CELLS

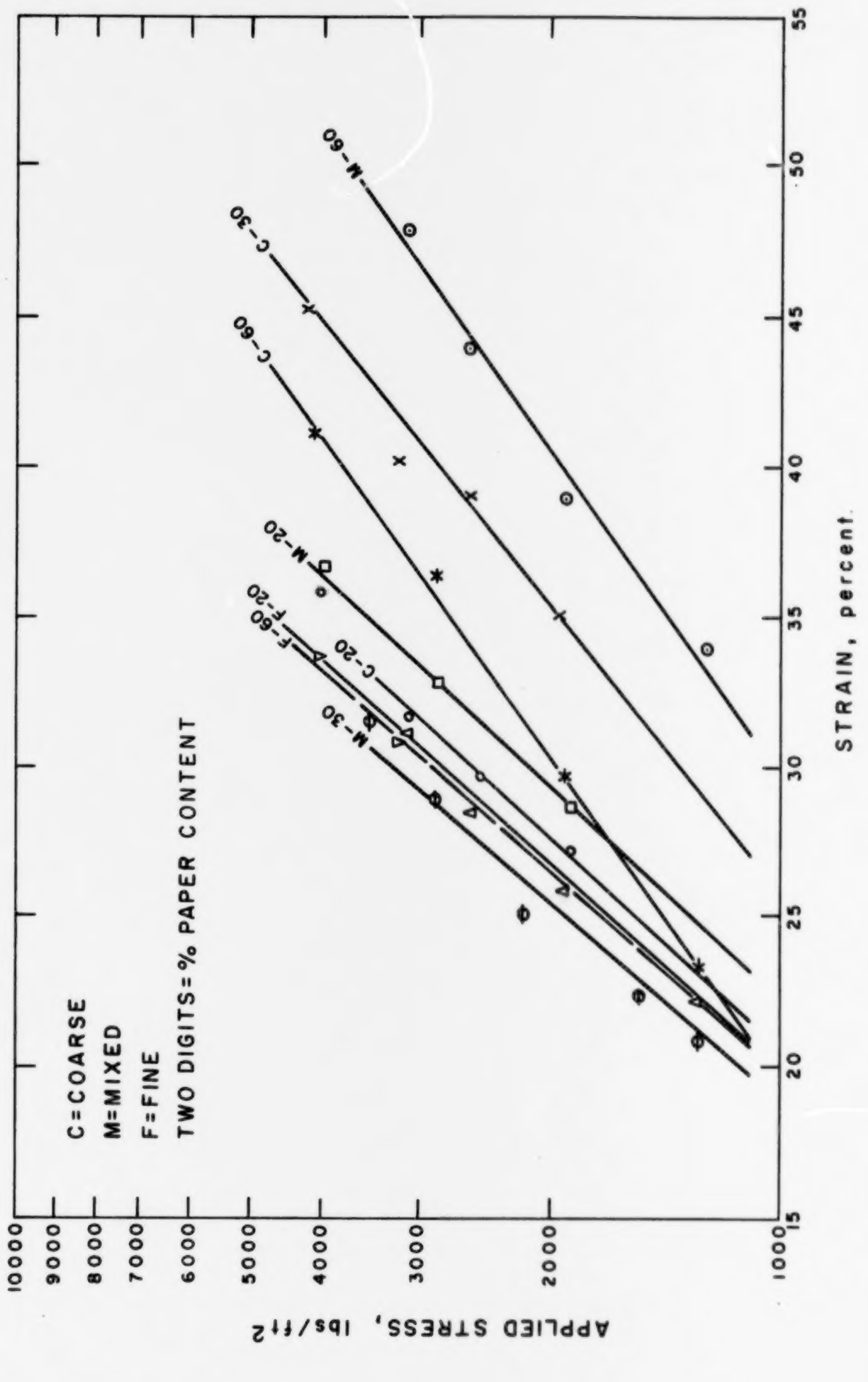


FIGURE II-41

STRESS—STRAIN CURVES: AEROBIC REFUSE CELLS, 65 PERCENT SATURATED

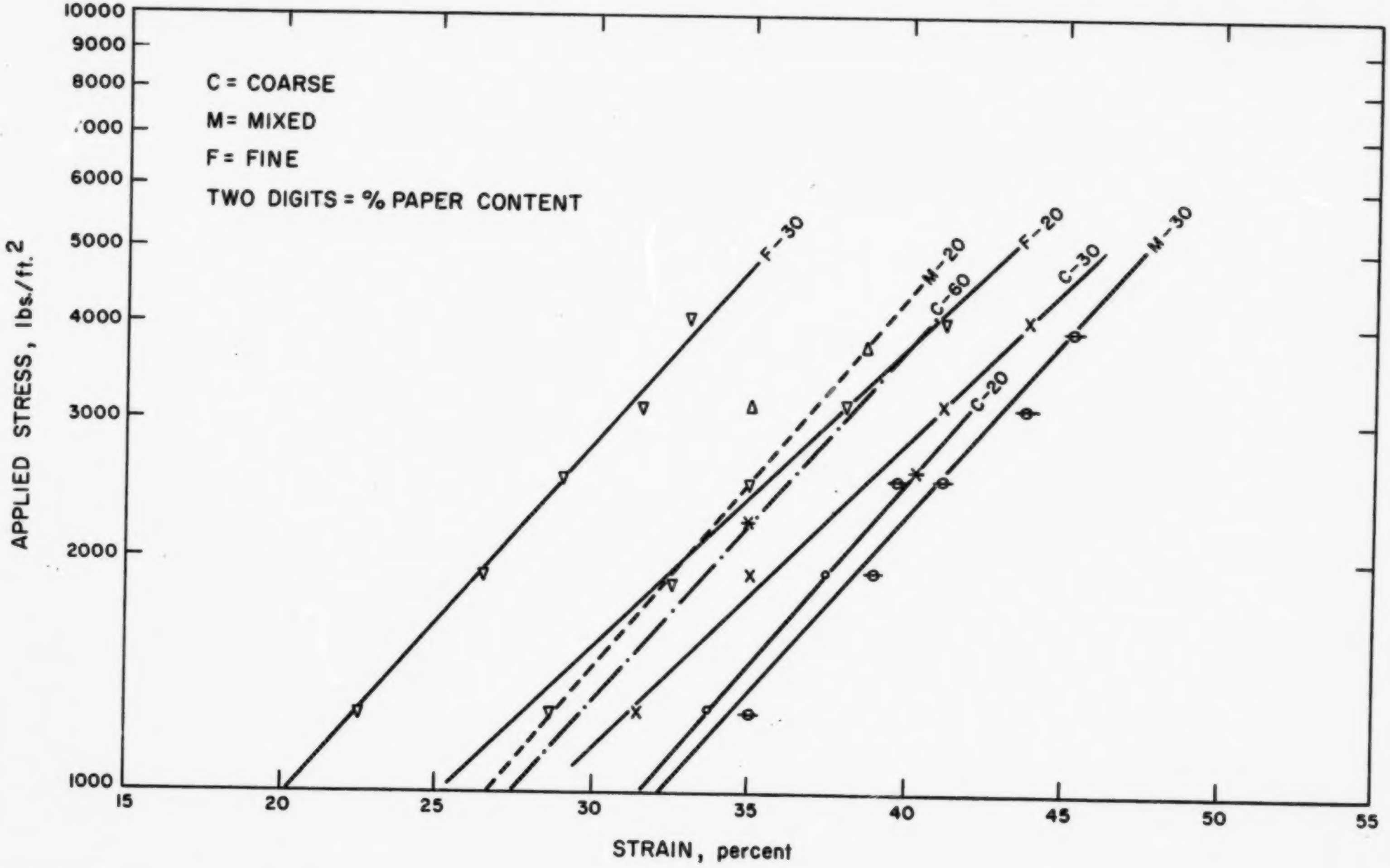


FIGURE II-42

STRESS-STRAIN CURVES: ANAEROBIC REFUSE CELLS, 65 PERCENT SATURATED

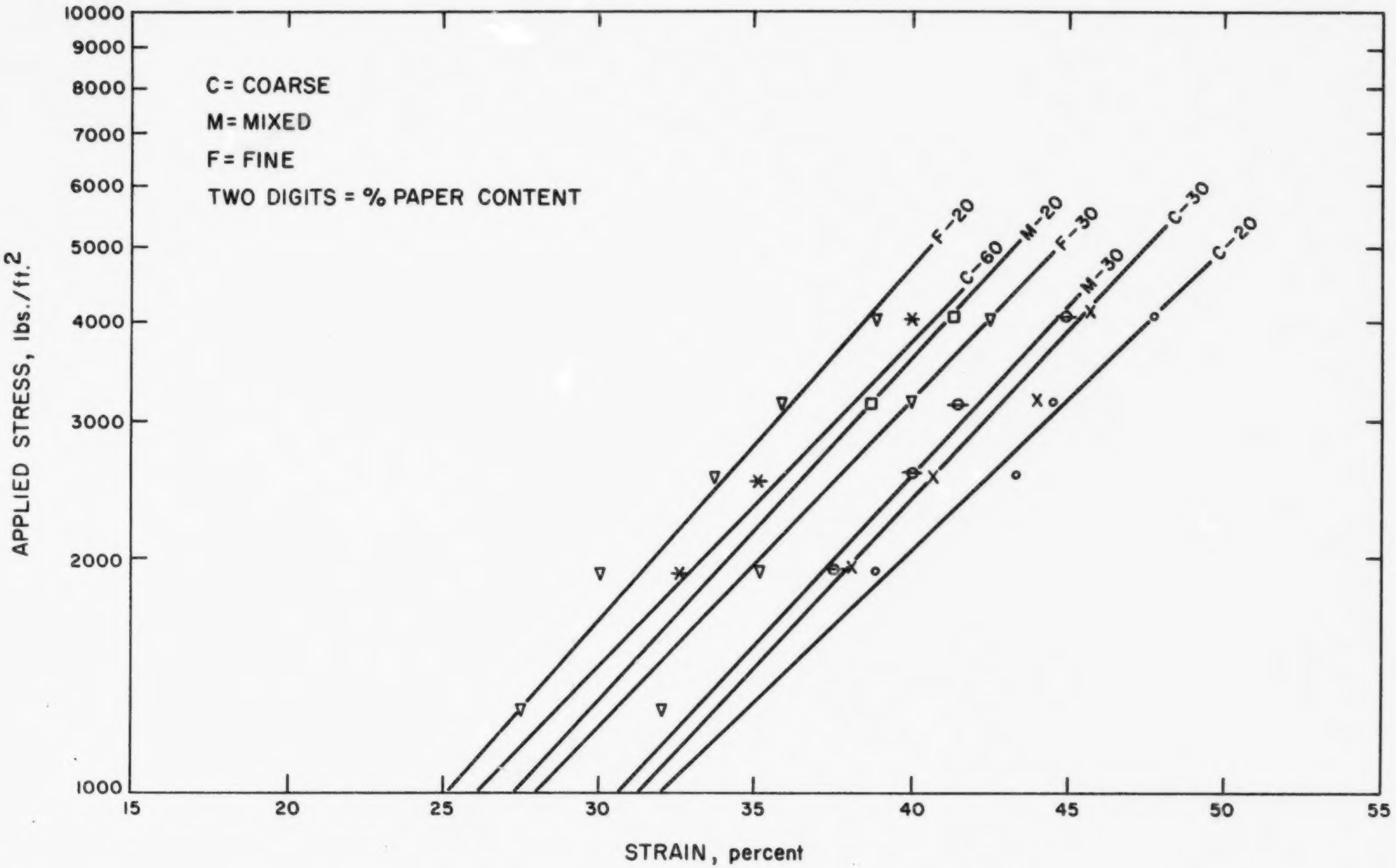


FIGURE II-43

STRESS–STRAIN CURVES: ANAEROBIC SATURATED REFUSE CELLS

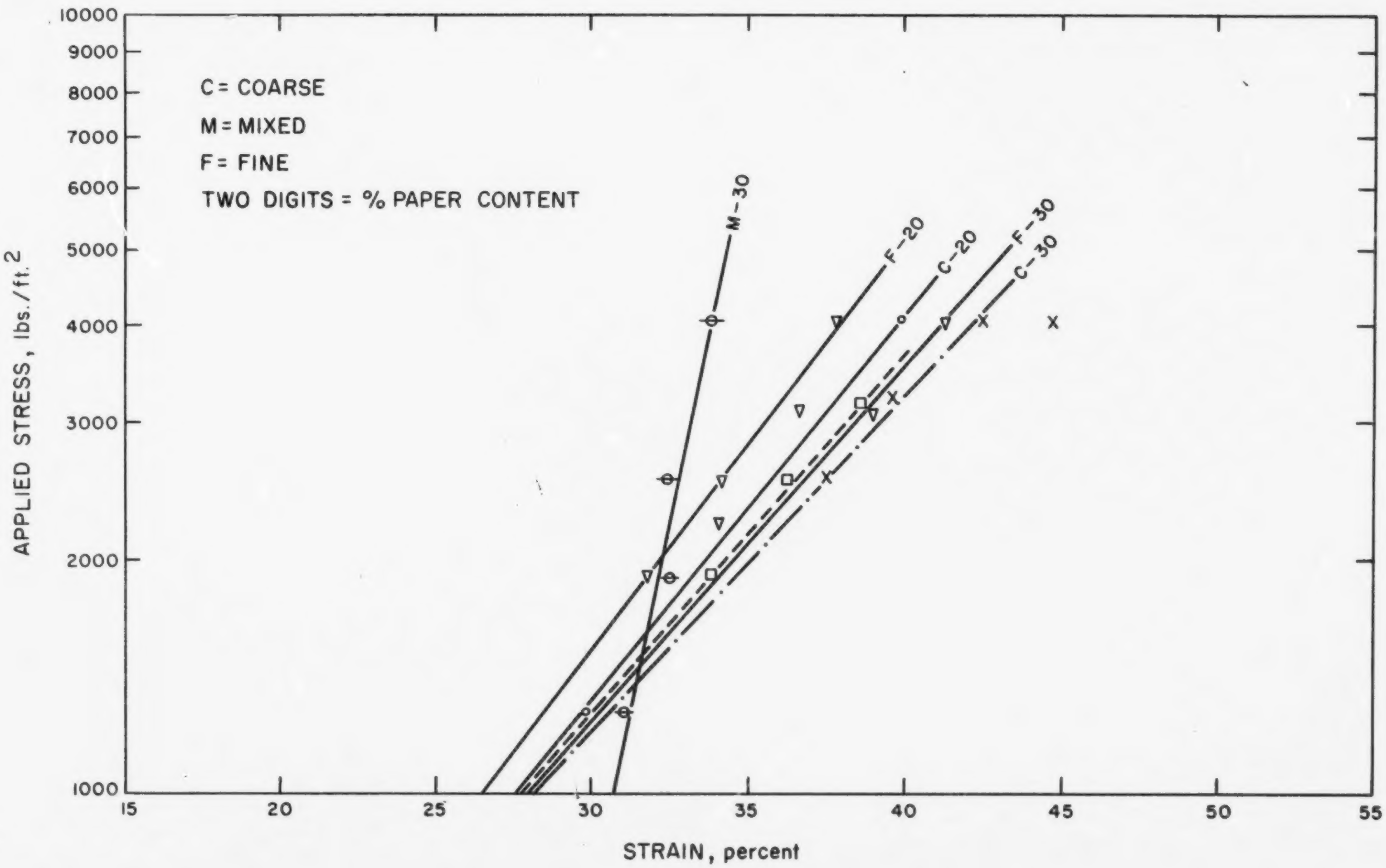
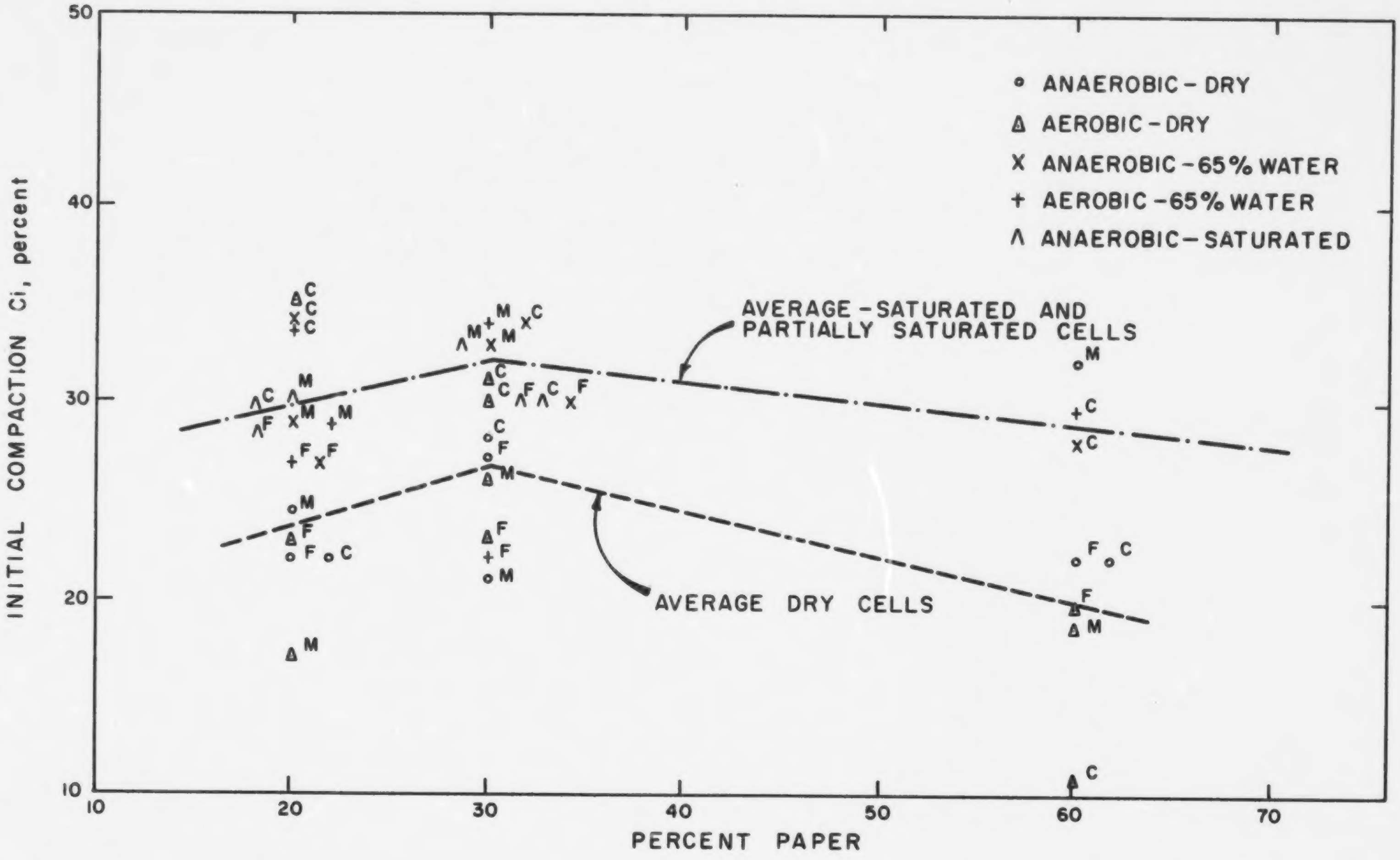


FIGURE II-44

VARIATION OF INITIAL COMPACTION WITH PAPER CONTENT



NOTE: Initial Surcharge 1260 lb/sq.ft.

FIGURE II-45

RELATIONSHIP BETWEEN UNIT WEIGHT RATIO AND INITIAL COMPACTION

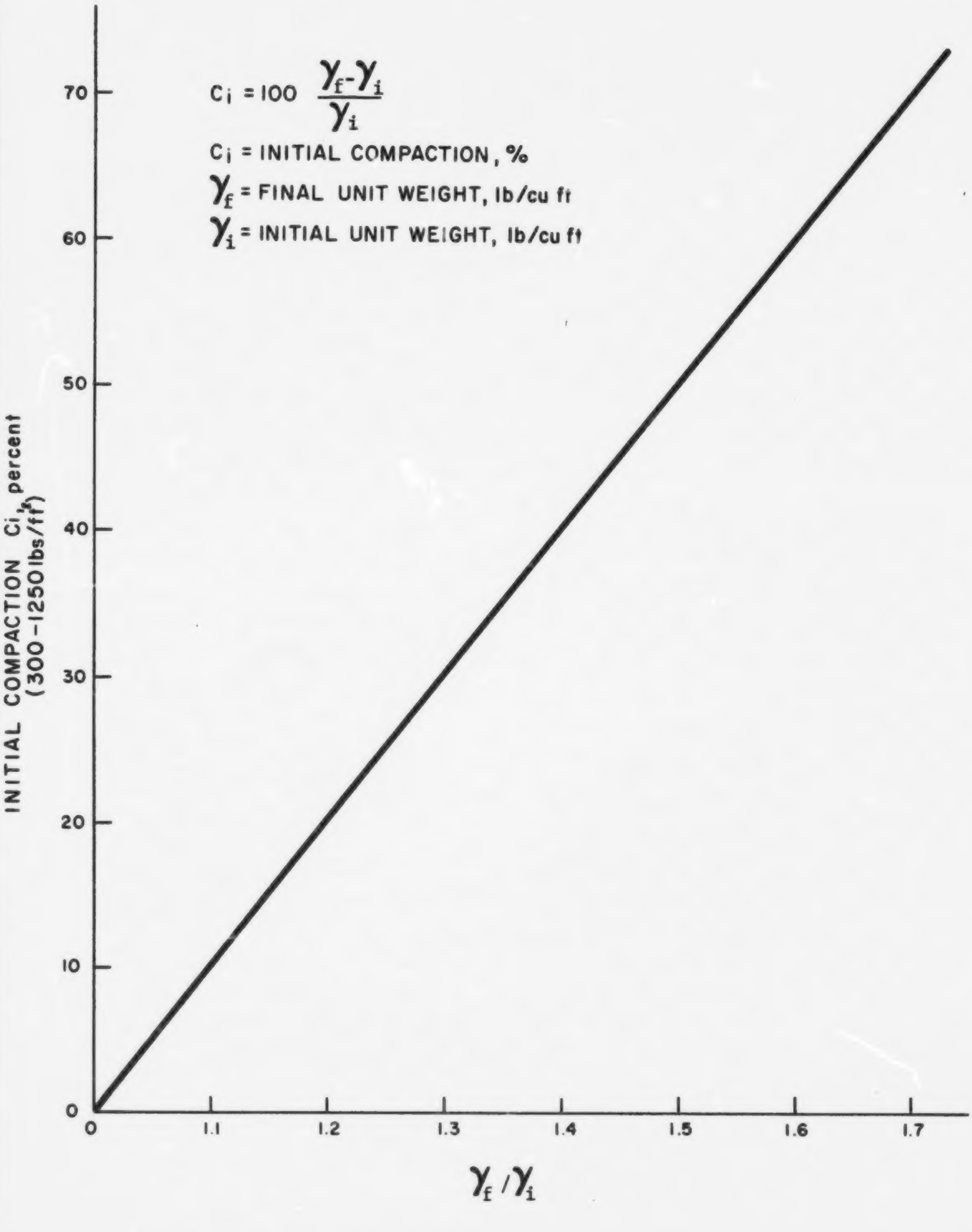
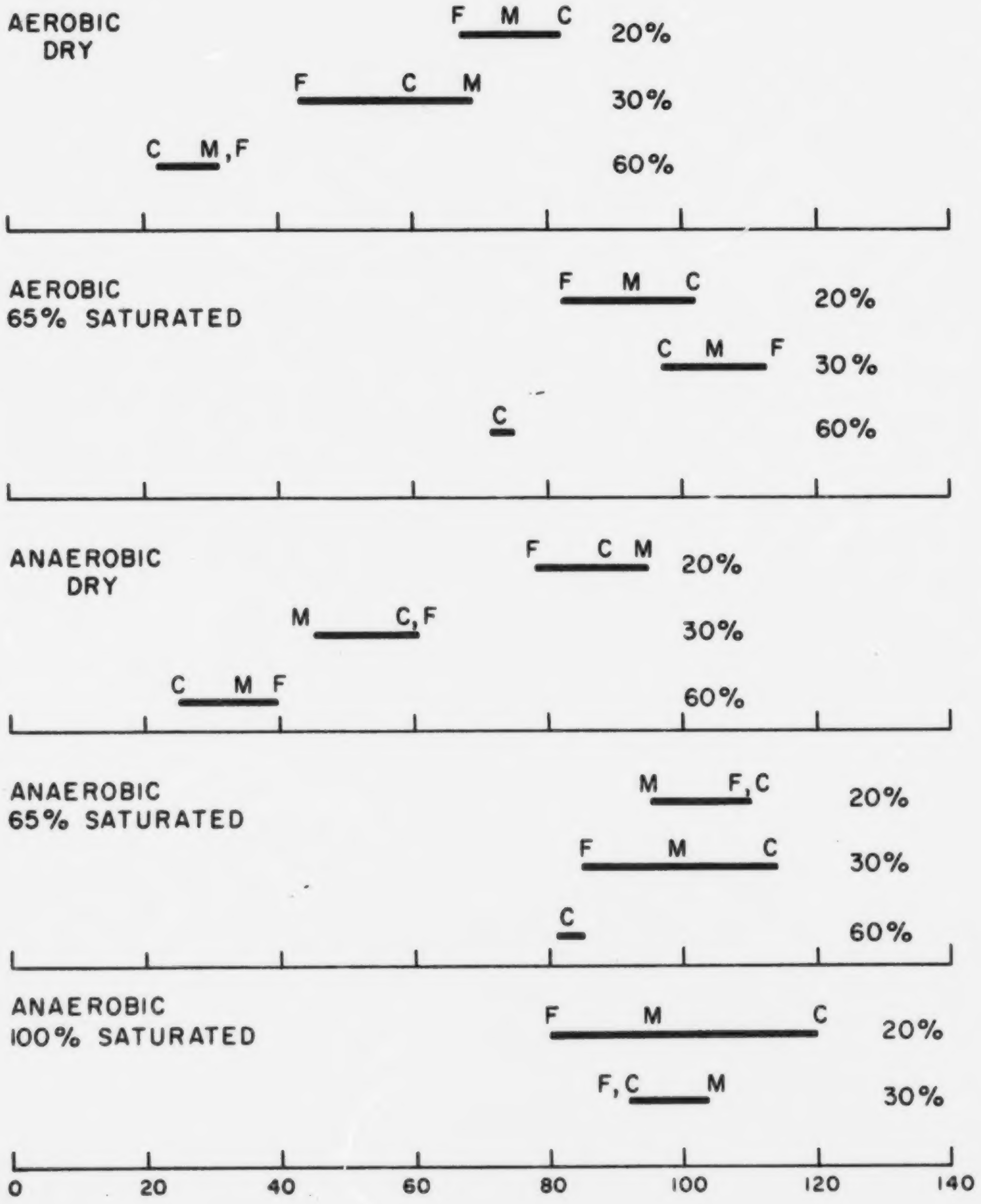


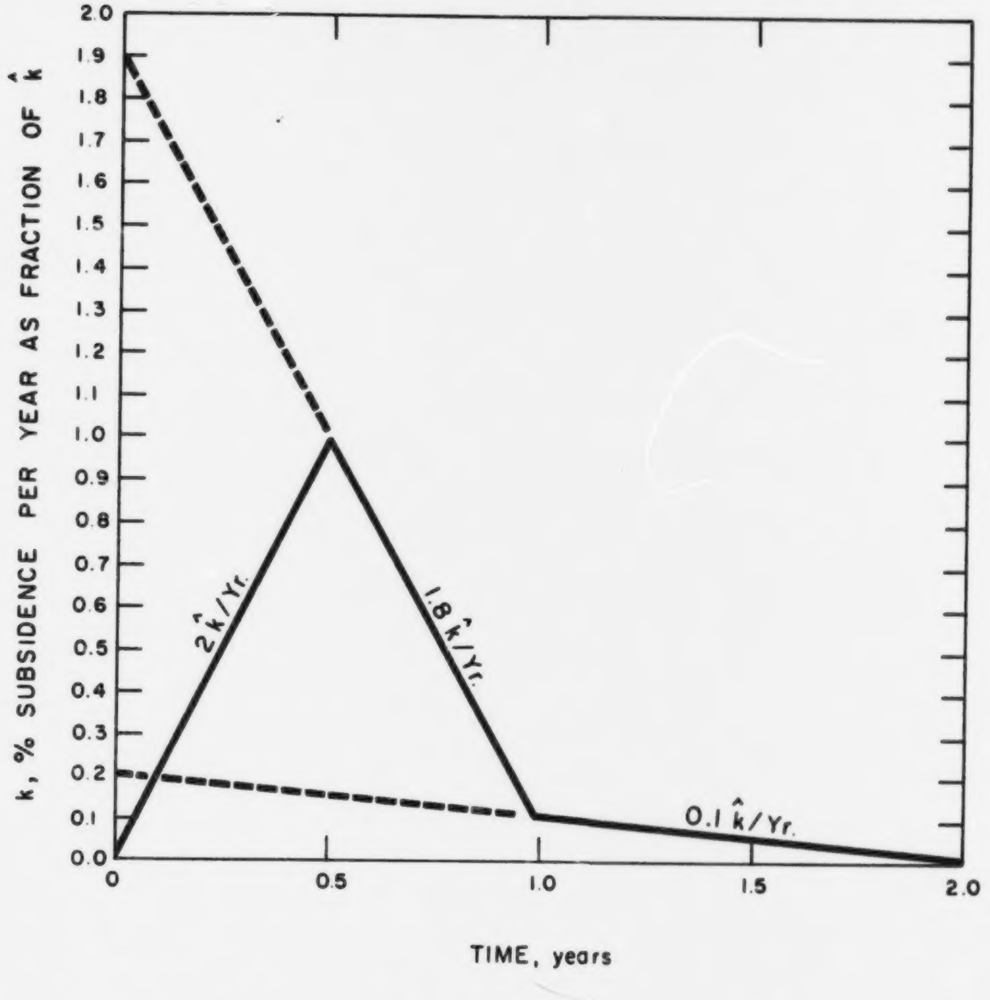
FIGURE II-46

UNIT WEIGHT AT COMPACTION STRESS OF 1260 LB/SQ. FT. FOR REFUSE CELLS



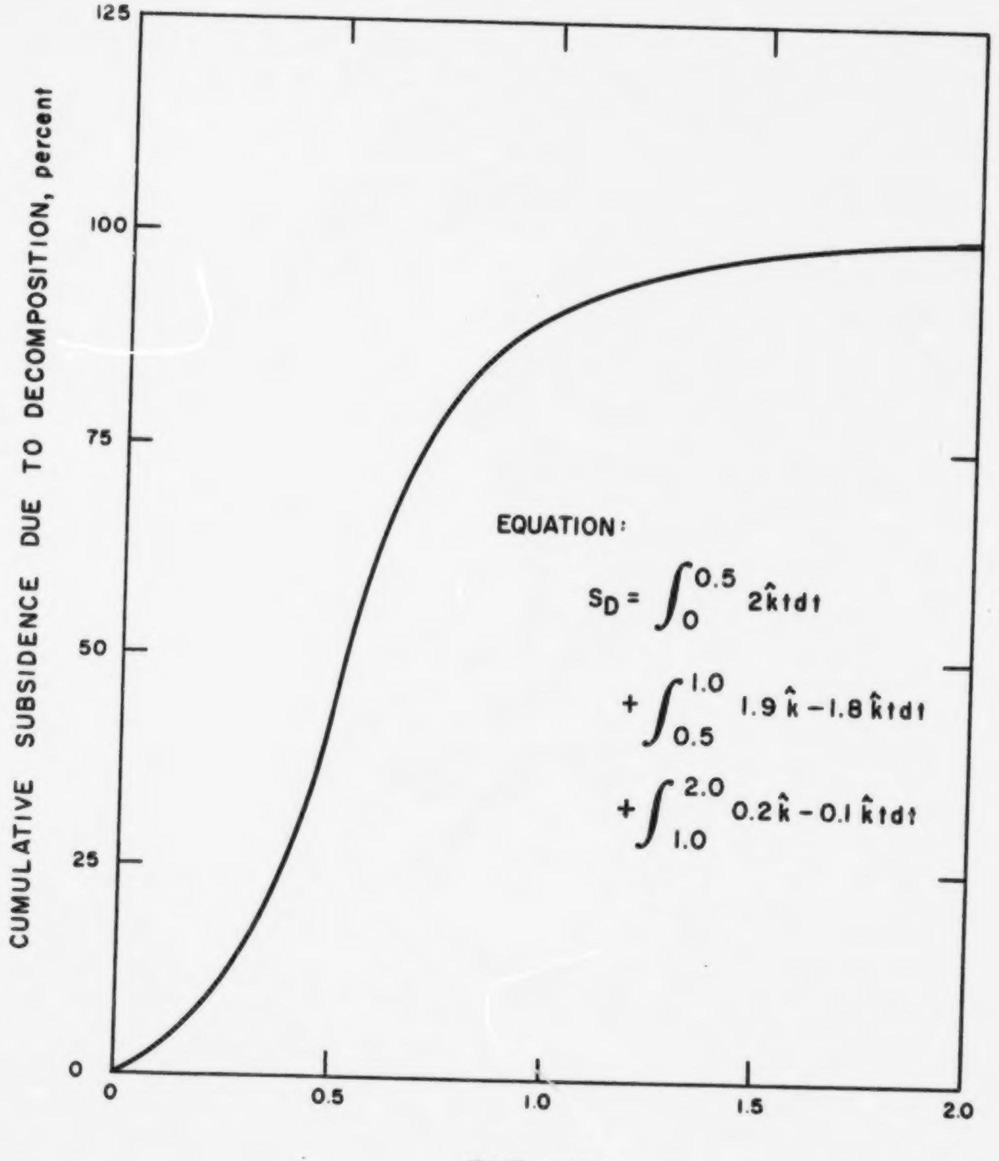
%= PERCENT PAPER CONTENT; F= FINE SIZE; M= MIXED SIZE; C= COARSE SIZE

TIME VARIATION OF SUBSIDENCE RATE DUE TO DECOMPOSITION



NOTE: $\hat{k}$ = Average annual rate of subsidence observed at 180 days, % per year

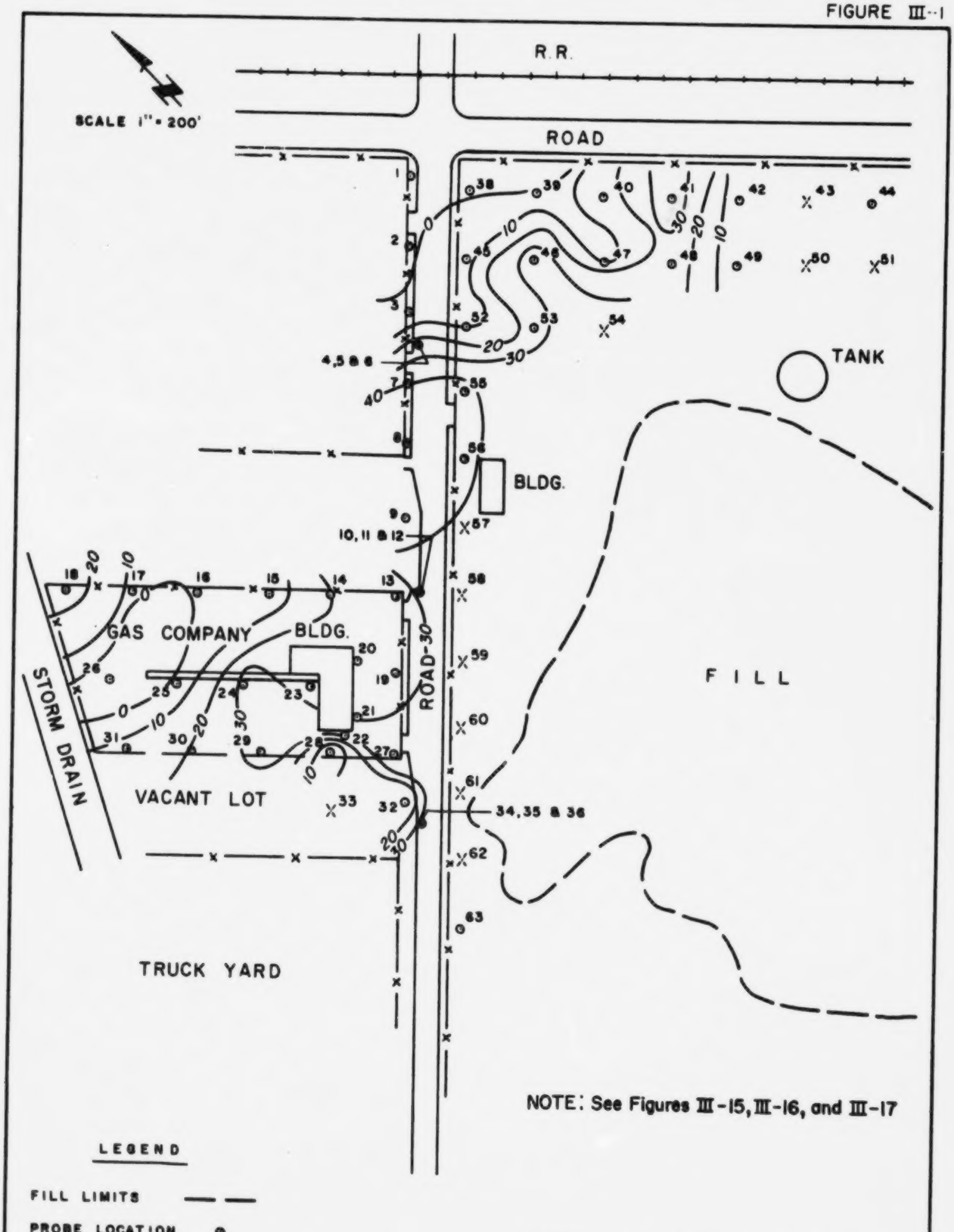
CUMULATIVE SUBSIDENCE DUE TO DECOMPOSITION



$$S_D = \int_{0}^{0.5} 2\hat{k}t\,dt + \int_{0.5}^{1.0} 1.9\hat{k} - 1.8\hat{k}t\,dt + \int_{1.0}^{2.0} 0.2\hat{k} - 0.1\hat{k}t\,dt$$

NOTE: $\hat{k}$ = Average annual rate of subsidence observed at 180 days, % per year.

FIGURE III-1


SCALE 1" = 200'
R.R.
ROAD
ROAD-30
TANK
BLDG.
FILL
GAS COMPANY BLDG.
STORM DRAIN
VACANT LOT
TRUCK YARD
4,5 & 6
10, 11 & 12
34, 35 & 36
0
10
20
30
40
1
2
3
7
8
9
13
14
15
16
17
18
19
20
21
22
23
24
25
26
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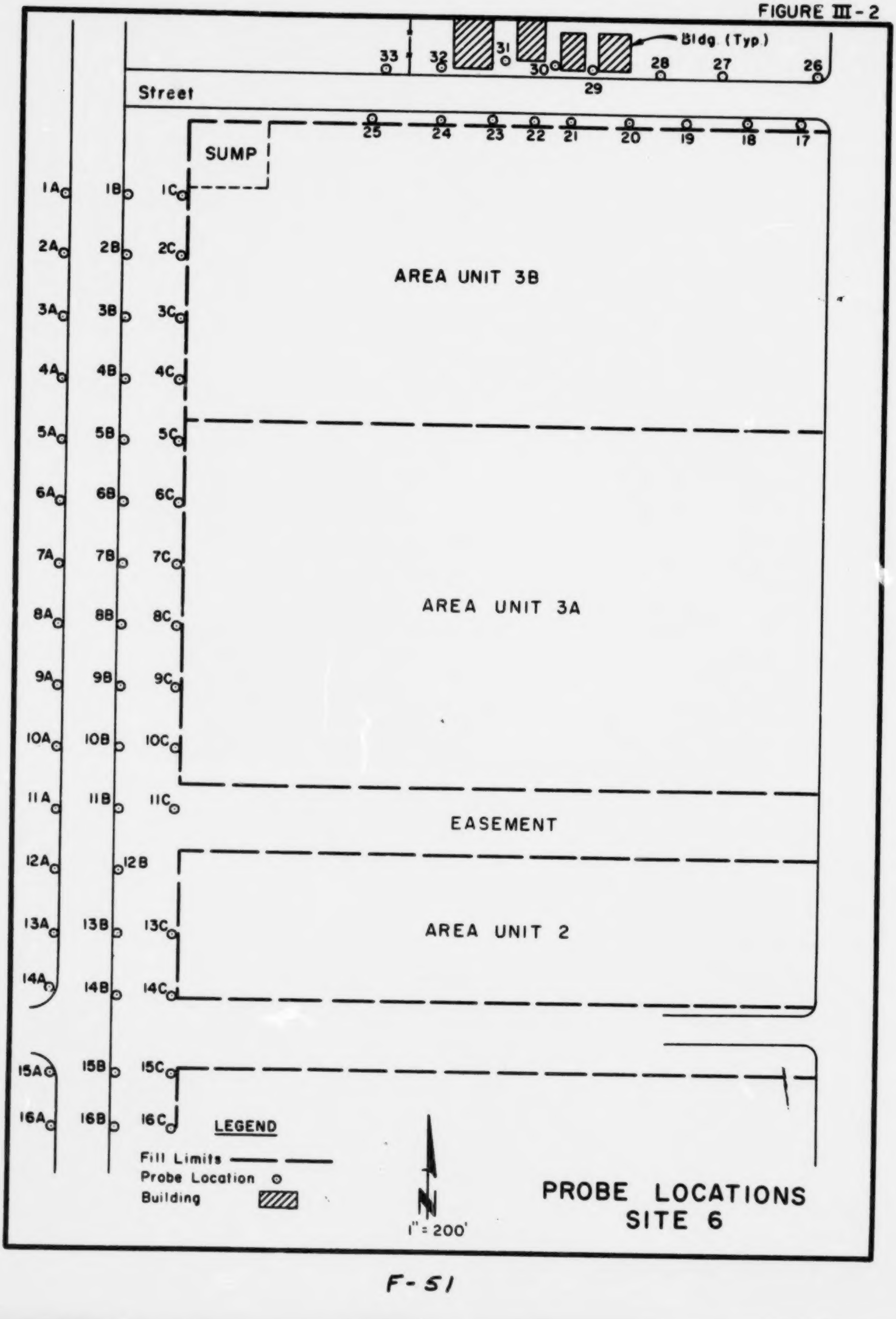
28
29
30
31
32
33
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
NOTE: See Figures III-15, III-16, and III-17
LEGEND
FILL LIMITS — —
PROBE LOCATION ⊙
PROBE IN MANHOLE ●
PROBE LOST X

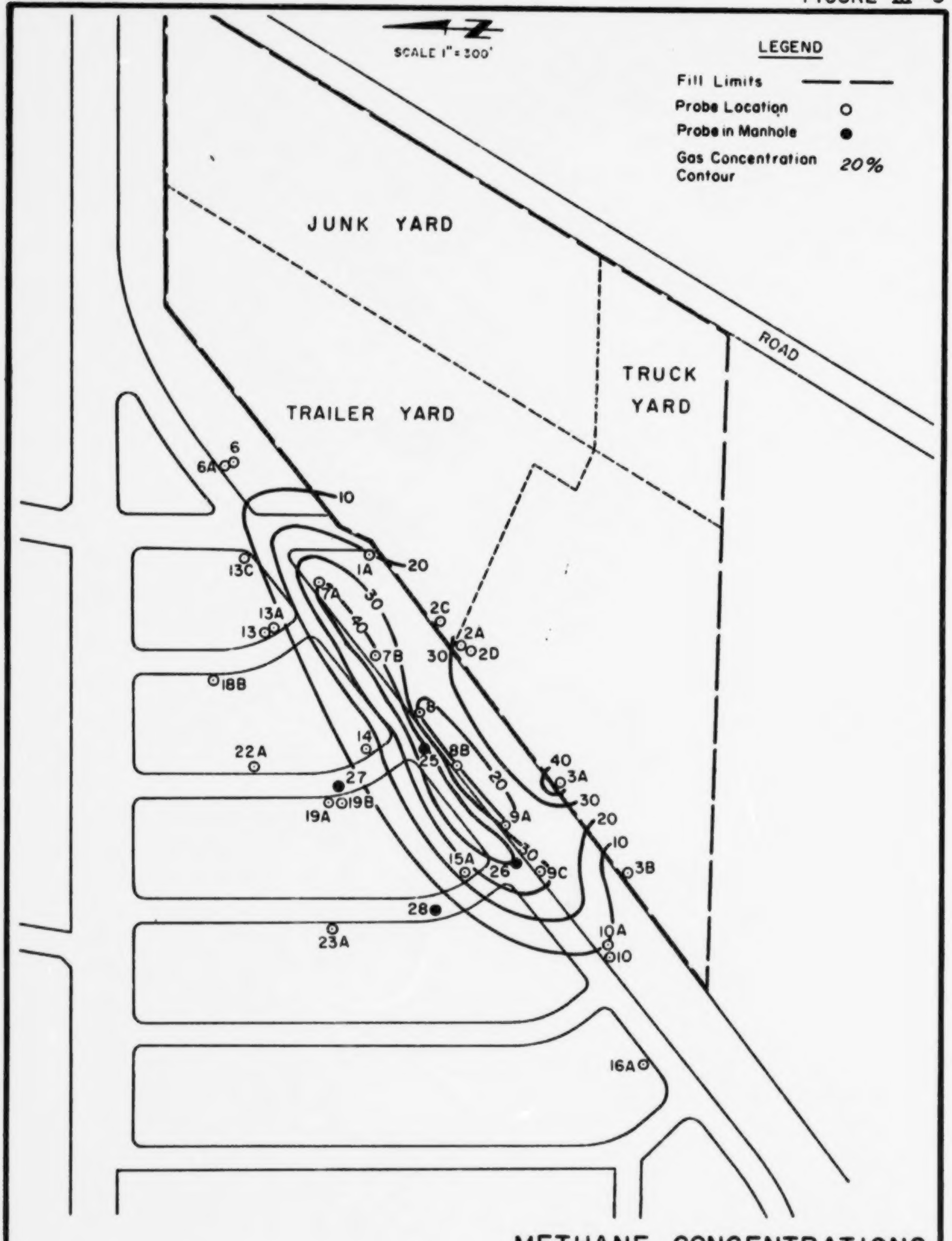
METHANE CONCENTRATIONS
28 MAY 1969
SITE 1

FIGURE III-2


Bldg. (Typ)
33
32
31
30
29
28
27
26
Street
SUMP
25
24
23
22
21
20
19
18
17
1A
1B
1C
2A
2B
2C
AREA UNIT 3B
3A
3B
3C
4A
4B
4C
5A
5B
5C
6A
6B
6C
7A
7B
7C
AREA UNIT 3A
8A
8B
8C
9A
9B
9C
10A
10B
10C
11A
11B
11C
EASEMENT
12A
12B
13A
13B
13C
AREA UNIT 2
14A
14B
14C
15A
15B
15C
16A
16B
16C
LEGEND
Fill Limits
Probe Location ⊙
Building ▨
N
1" = 200'

PROBE LOCATIONS
SITE 6

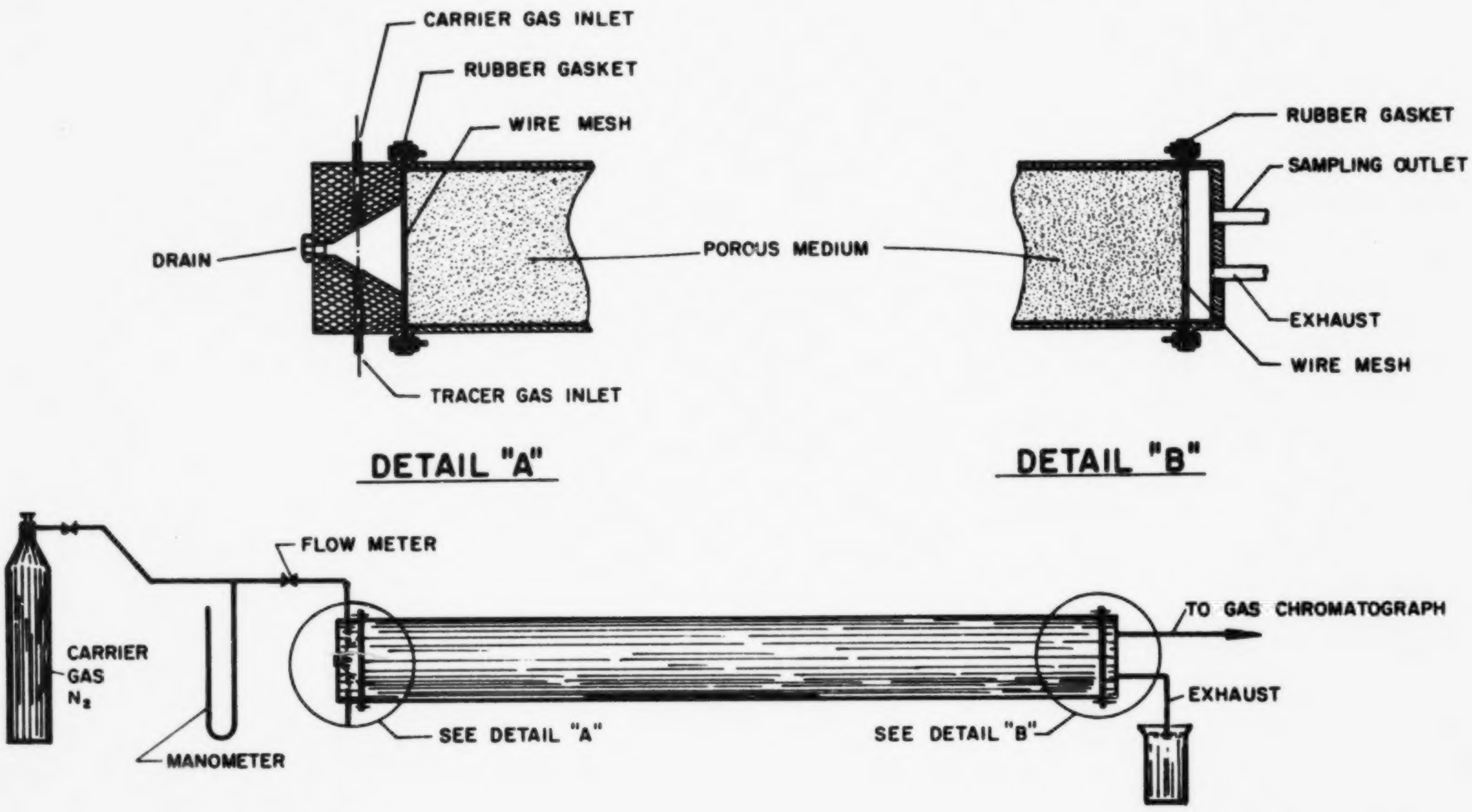
FIGURE III-3



SCALE 1" = 300'
LEGEND
Fill Limits
Probe Location ○
Probe in Manhole ●
Gas Concentration Contour 20%
JUNK YARD
TRUCK YARD
TRAILER YARD
ROAD
6
6A
10
20
30
40
13C
1A
7A
13A
13
2C
2A
2D
7B
18B
8
8B
14
22A
25
27
19A
19B
3A
9A
15A
26
9C
3B
28
10A
23A
16A

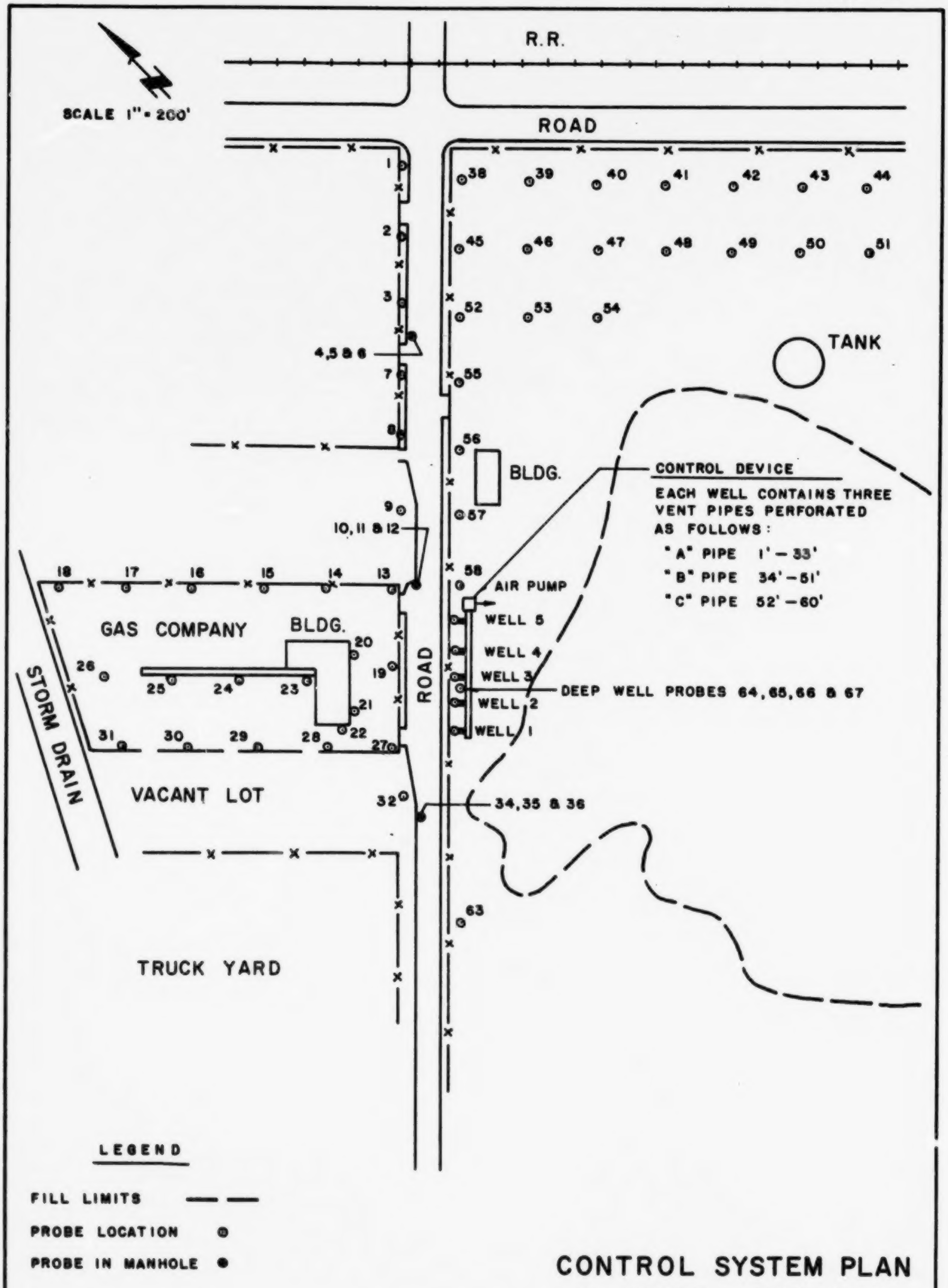
METHANE CONCENTRATIONS
17 SEPTEMBER 1969
SITE 8

FIGURE III-4

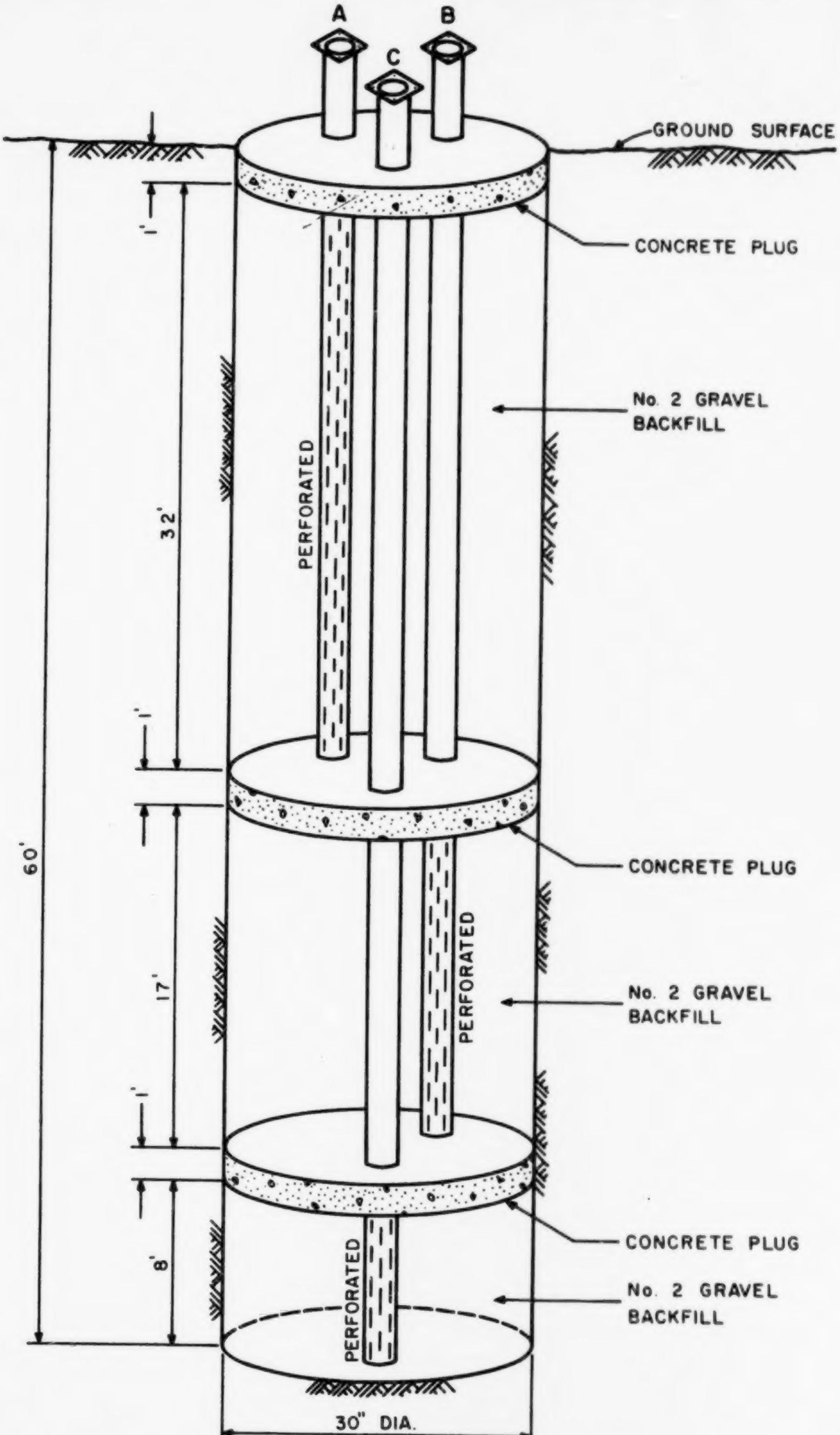

CARRIER GAS INLET
RUBBER GASKET
WIRE MESH
DRAIN
POROUS MEDIUM
TRACER GAS INLET
DETAIL "A"
RUBBER GASKET
SAMPLING OUTLET
EXHAUST
WIRE MESH
DETAIL "B"
FLOW METER
CARRIER GAS N_2
MANOMETER
SEE DETAIL "A"
SEE DETAIL "B"
TO GAS CHROMATOGRAPH
EXHAUST

SCHEMATIC DIAGRAM OF LABORATORY UNIT FOR STUDY OF GAS DIFFUSION IN POROUS MEDIA

FIGURE III-5


R.R.
SCALE 1" = 200'
ROAD
ROAD
TANK
BLDG.
CONTROL DEVICE
EACH WELL CONTAINS THREE VENT PIPES PERFORATED AS FOLLOWS:
"A" PIPE 1' – 33'
"B" PIPE 34' – 51'
"C" PIPE 52' – 60'
AIR PUMP
WELL 5
WELL 4
WELL 3
WELL 2
WELL 1
DEEP WELL PROBES 64, 65, 66 & 67
GAS COMPANY
BLDG.
STORM DRAIN
VACANT LOT
TRUCK YARD
4, 5 & 6
10, 11 & 12
34, 35 & 36
1
2
3
7
8
9
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
63
LEGEND
FILL LIMITS
PROBE LOCATION
PROBE IN MANHOLE

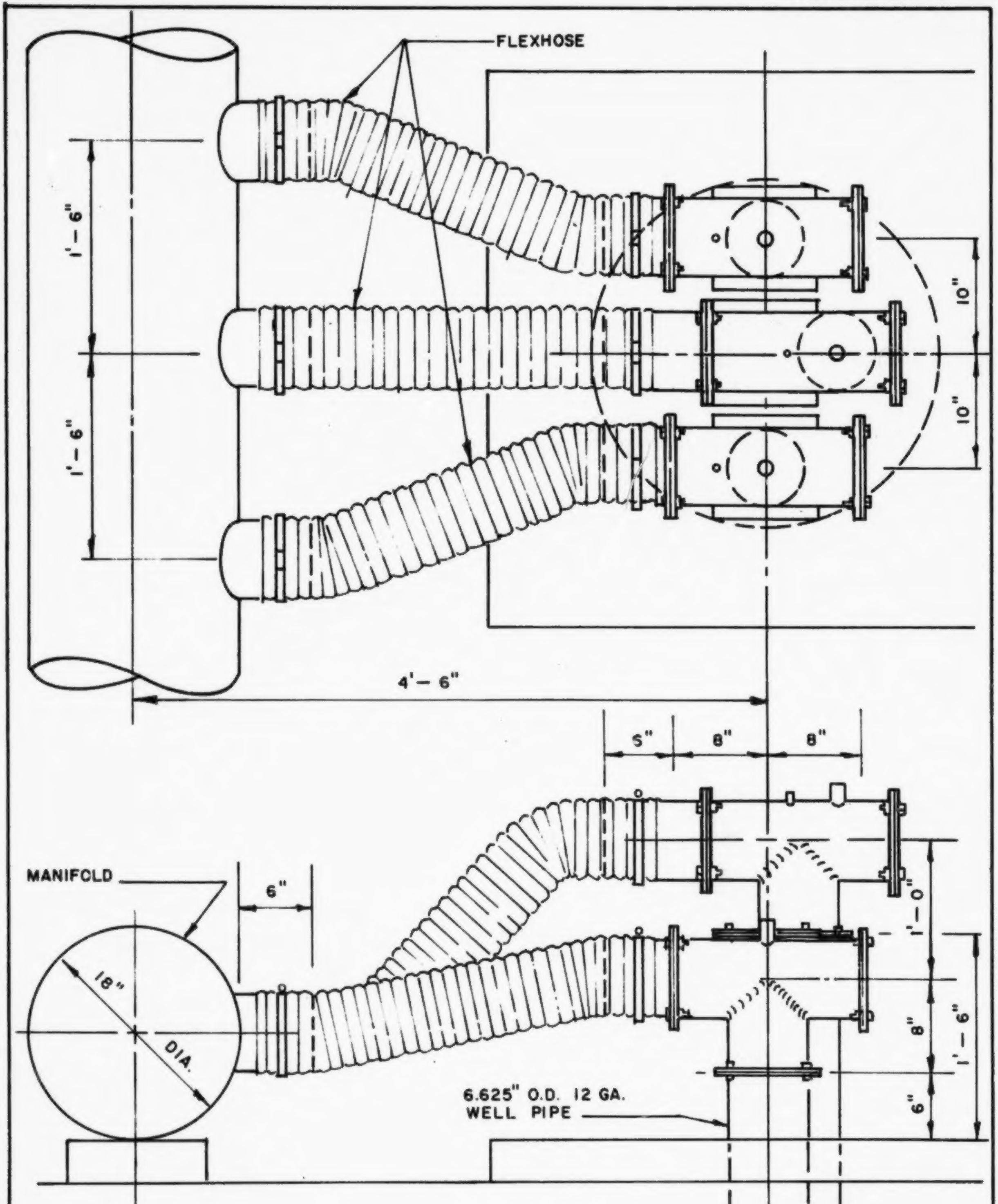
CONTROL SYSTEM PLAN
& PROBE LOCATION
SITE I


A
B
C
GROUND SURFACE
CONCRETE PLUG
1'
32'
PERFORATED
No. 2 GRAVEL BACKFILL
1'
60'
CONCRETE PLUG
17'
PERFORATED
No. 2 GRAVEL BACKFILL
1'
CONCRETE PLUG
8'
PERFORATED
No. 2 GRAVEL BACKFILL
30" DIA.

GAS CONTROL SYSTEM
TYPICAL VENT WELL
SITE I

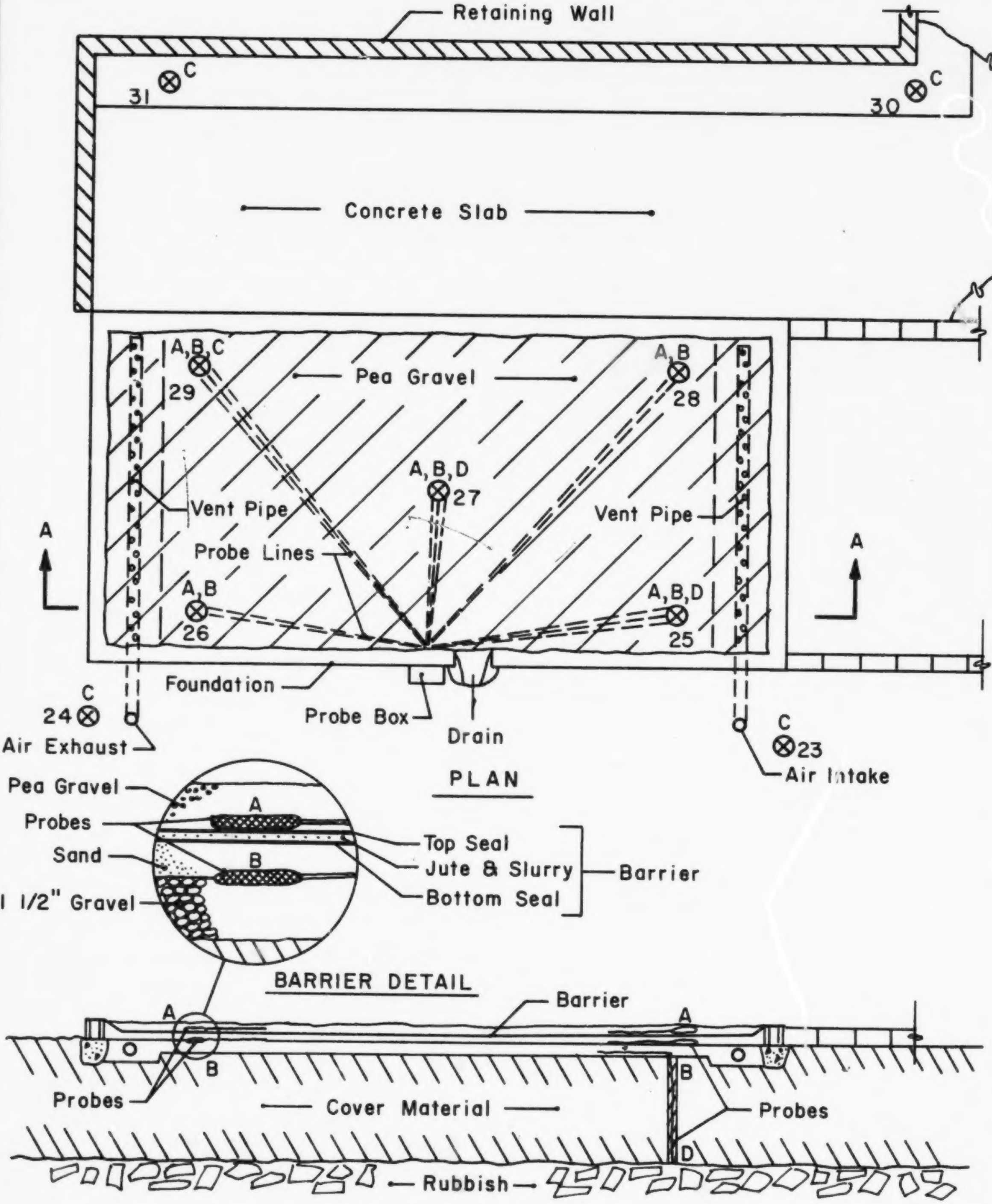
(No Scale)

FIGURE III-7


FLEXHOSE
1'-6"
1'-6"
10"
10"
4'-6"
5"
8"
8"
MANIFOLD
6"
18" DIA.
1'-0"
8"
1'-6"
6"
6.625" O.D. 12 GA. WELL PIPE

GAS CONTROL SYSTEM
TEE TO MANIFOLD CONNECTION
SITE I

FIGURE III-8

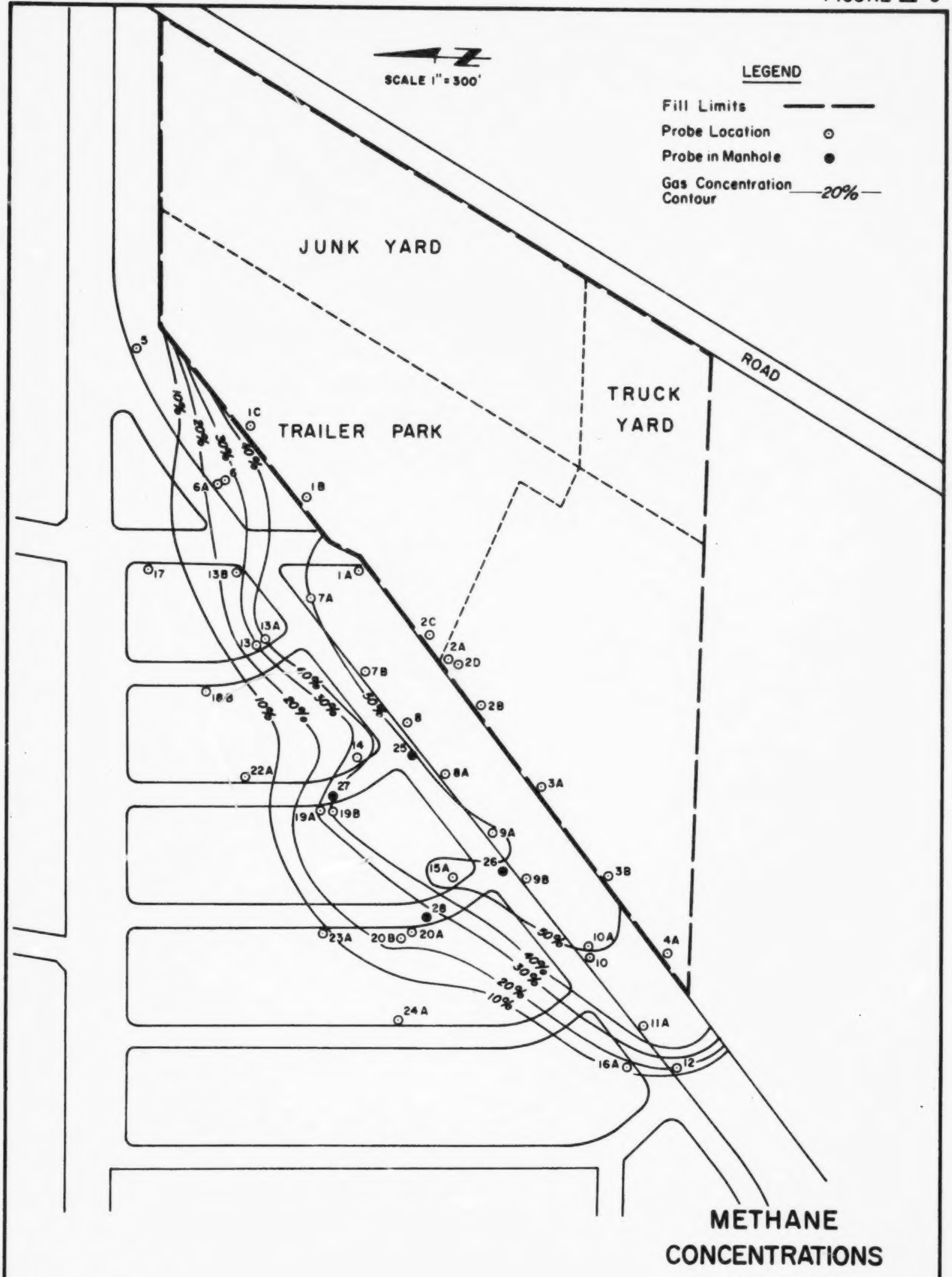

Retaining Wall
31 ⊗ C
30 ⊗ C
Concrete Slab
A,B,C ⊗ 29
Pea Gravel
A,B ⊗ 28
A,B,D ⊗ 27
Vent Pipe
Vent Pipe
Probe Lines
A
A
A,B ⊗ 26
A,B,D ⊗ 25
Foundation
C 24 ⊗
Air Exhaust
Probe Box
Drain
C ⊗ 23
Air Intake
PLAN
Pea Gravel
Probes
Sand
1 1/2" Gravel
A
B
Top Seal
Jute & Slurry
Bottom Seal
Barrier
BARRIER DETAIL
A
Barrier
A
B
B
Probes
Cover Material
Probes
D
Rubbish
SECTION A-A

GAS PROBE LOCATIONS = ⊗

A - Probe above barrier
B - Probe below barrier
C - Probe in cover material
D - Probe in rubbish

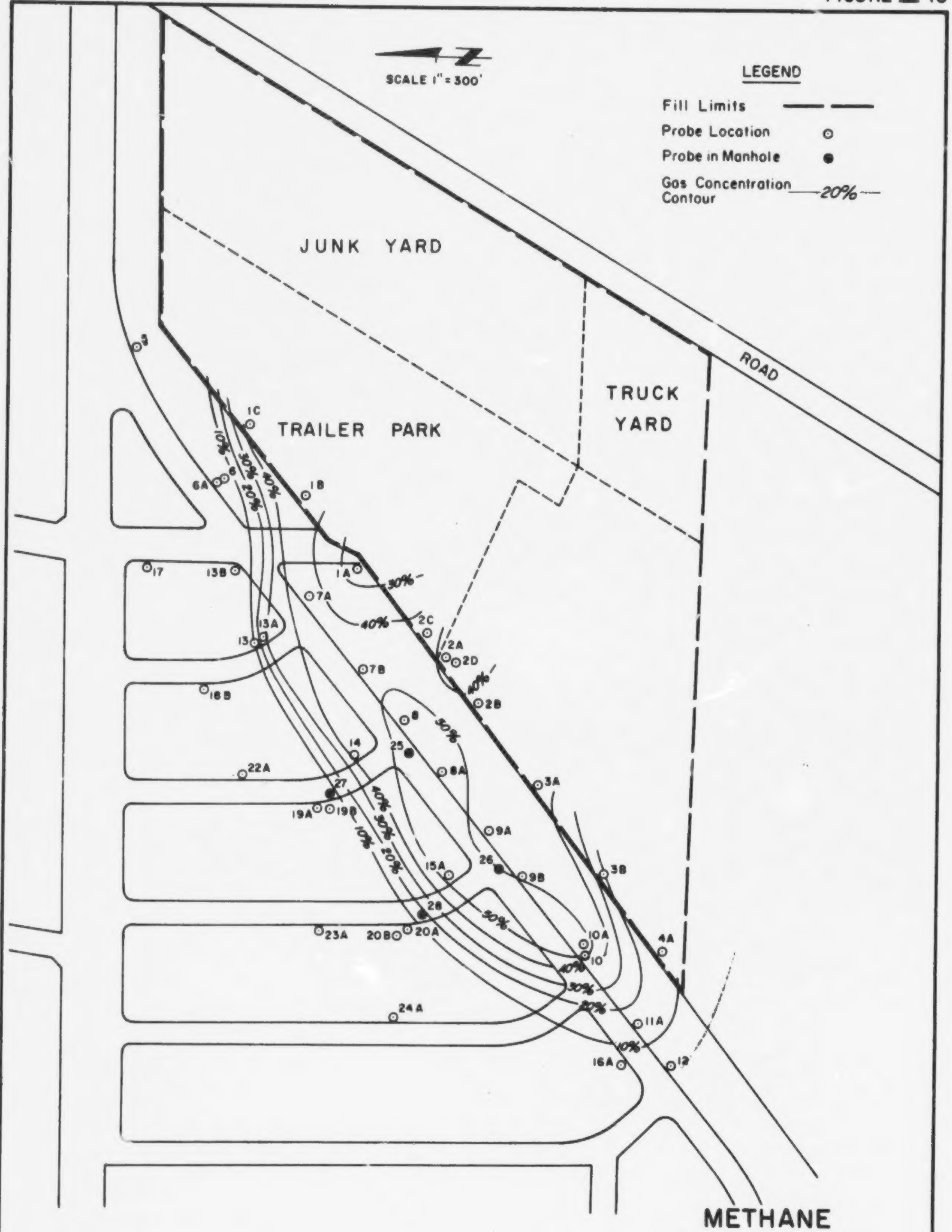
PROBE LOCATIONS
CONTROL SYSTEM
SITE 5

FIGURE III-9


N
SCALE 1" = 300'
LEGEND
Fill Limits
Probe Location ⊙
Probe in Manhole ●
Gas Concentration Contour 20%
JUNK YARD
TRUCK YARD
TRAILER PARK
ROAD
10%
20%
30%
40%
50%
5
1C
6A
6
1B
17
13B
1A
7A
13A
13
2C
2A
2D
7B
18B
2B
8
14
25
22A
8A
3A
27
19A
19B
9A
15A
26
9B
3B
28
23A
20B
20A
10A
4A
10
24A
11A
16A
12

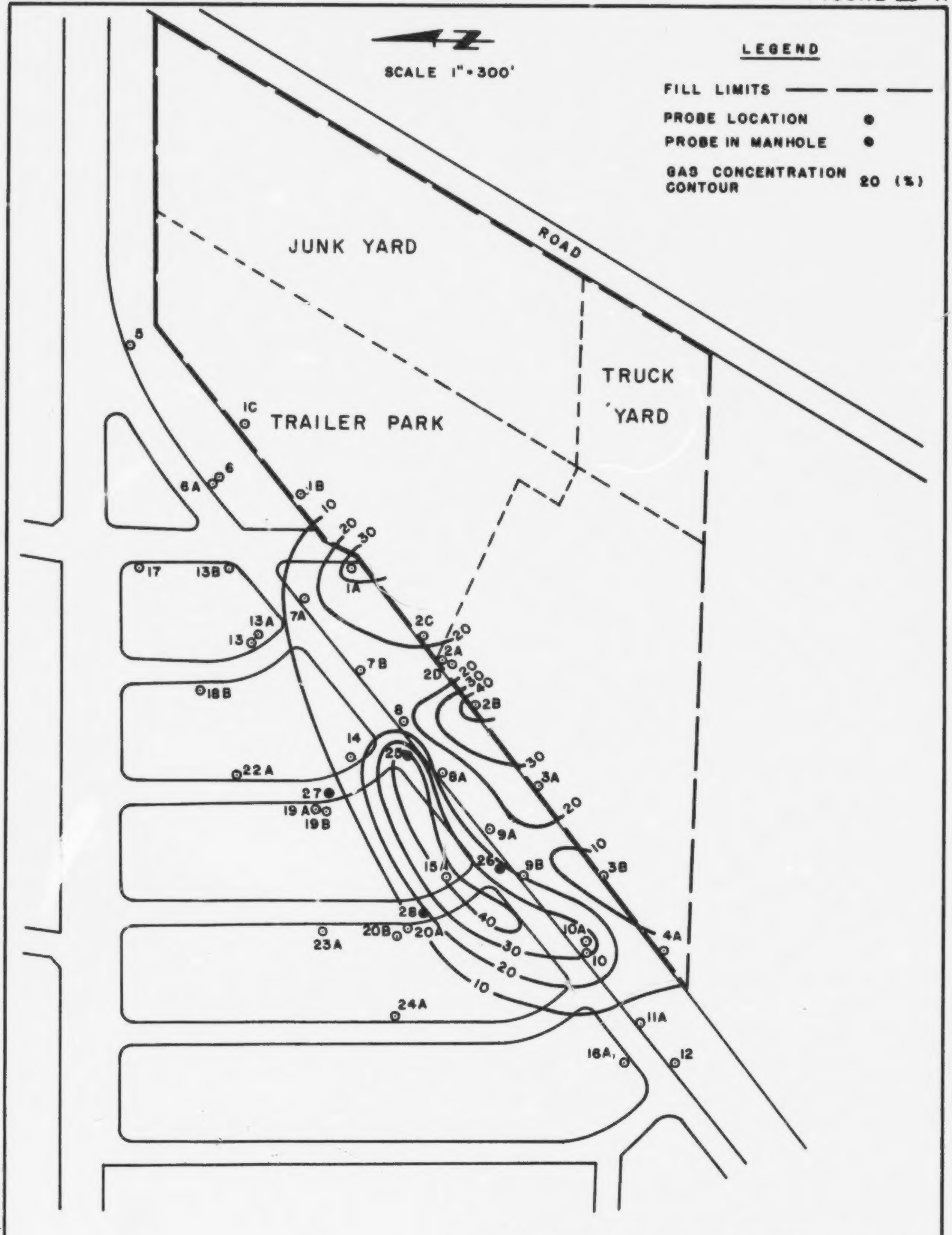
METHANE CONCENTRATIONS 9 MAY 1967 SITE 8

FIGURE III-10


N
SCALE 1" = 300'
LEGEND
Fill Limits
Probe Location ⊙
Probe in Manhole ●
Gas Concentration Contour —20%—
JUNK YARD
TRUCK YARD
TRAILER PARK
ROAD
5
1C
1B
1A
6A
6
17
13B
13A
13
7A
7B
2C
2A
2D
2B
18B
8
8A
25
14
22A
27
19A
19B
3A
9A
26
9B
15A
3B
28
23A
20B
20A
10A
10
4A
24A
11A
16A
12
10%
20%
30%
40%

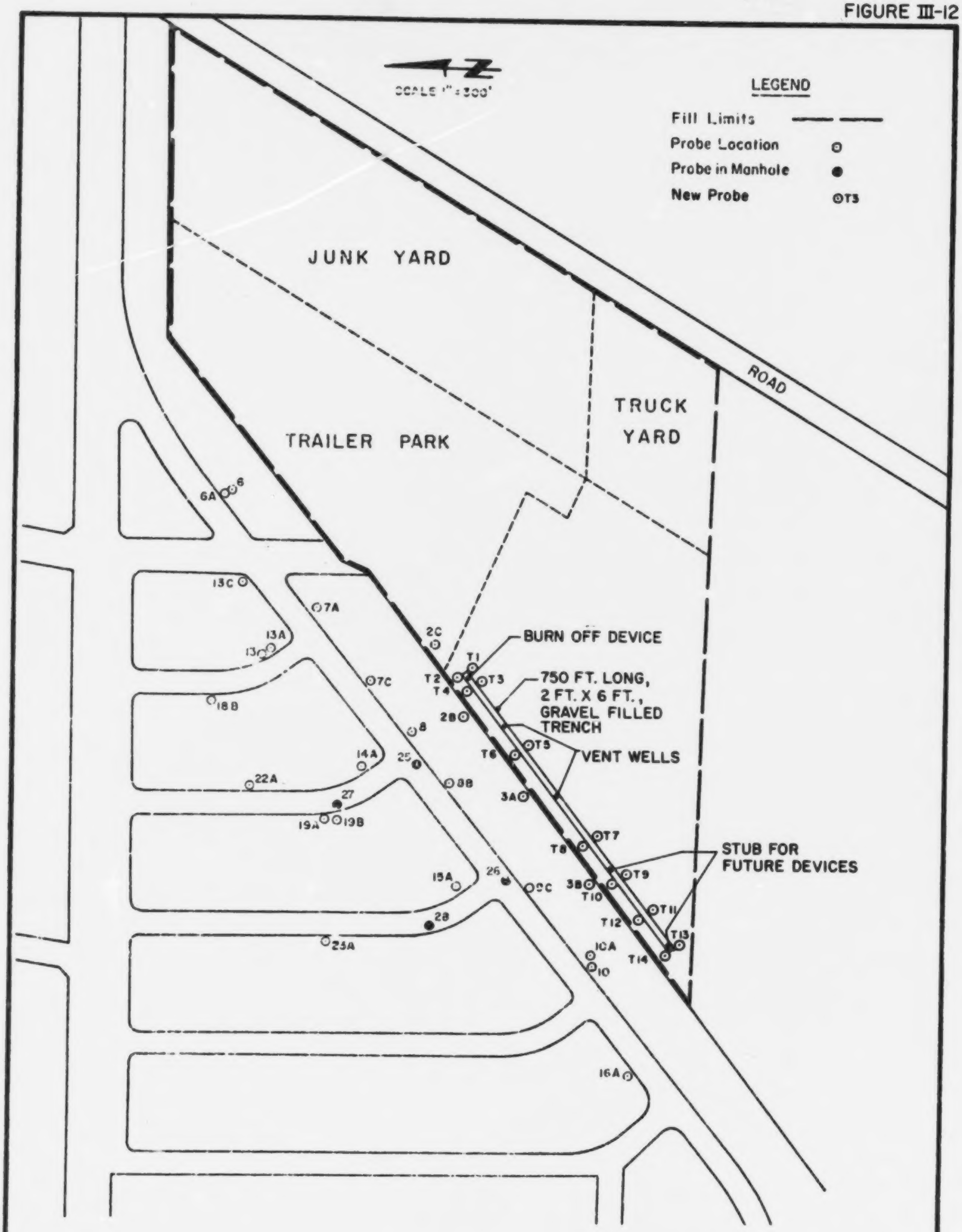
METHANE
CONCENTRATIONS
13 SEPTEMBER 1967
SITE 8

FIGURE III-11


N
SCALE 1" = 300'
LEGEND
FILL LIMITS
PROBE LOCATION ●
PROBE IN MANHOLE ●
GAS CONCENTRATION CONTOUR 20 (%)
ROAD
JUNK YARD
TRUCK YARD
TRAILER PARK
5
1C
6A
6
1B
10
20
30
1A
17
13B
7A
13A
13
2C
2A
7B
20
13A
2B
18B
8
14
25
8A
30
3A
22A
27
19A
19B
20
9A
10
15A
26
9B
3B
28
40
20B
20A
10A
4A
23A
30
20
10
10
24A
11A
16A
12

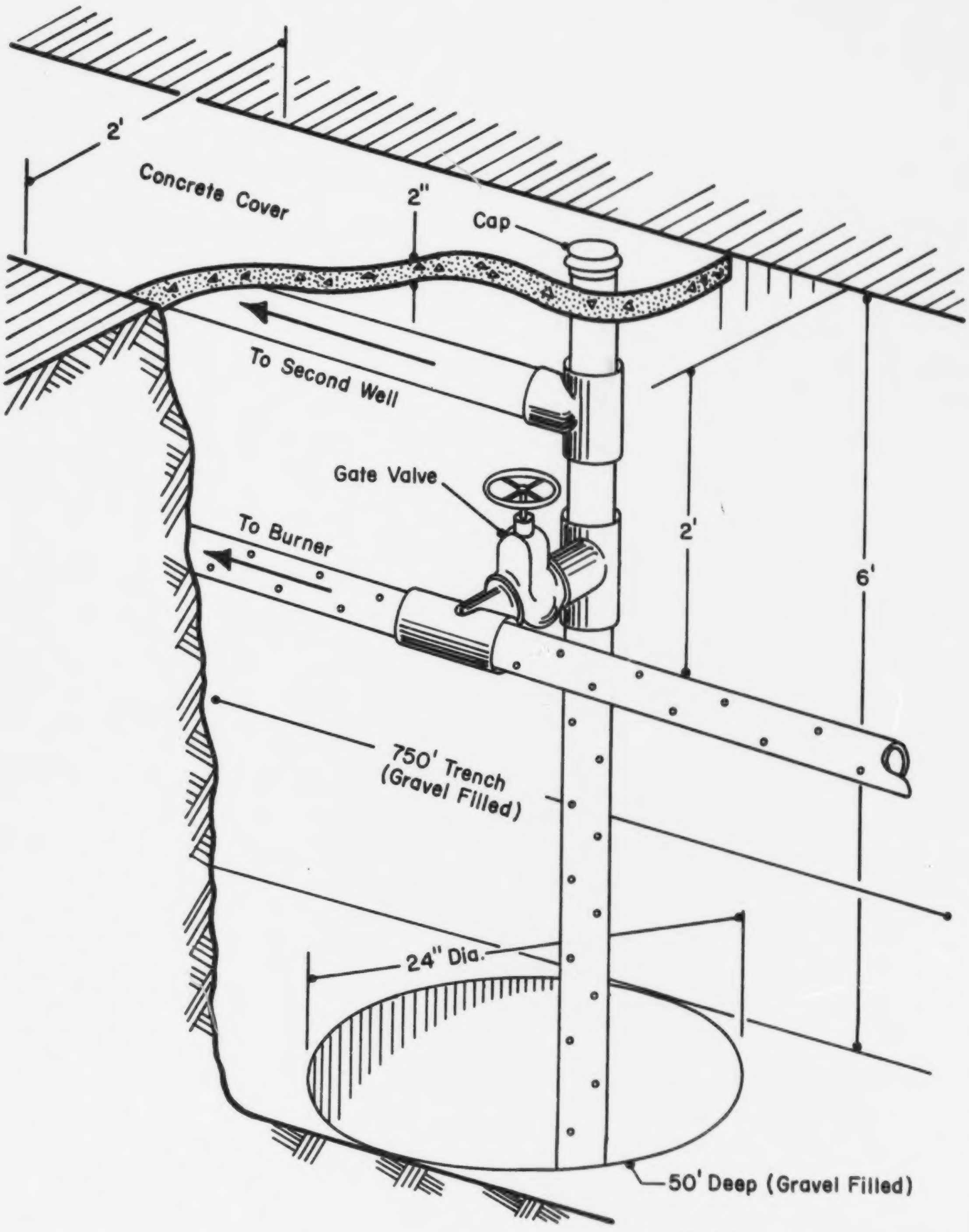
METHANE CONCENTRATIONS
18 NOVEMBER 1968
SITE 8

FIGURE III-12

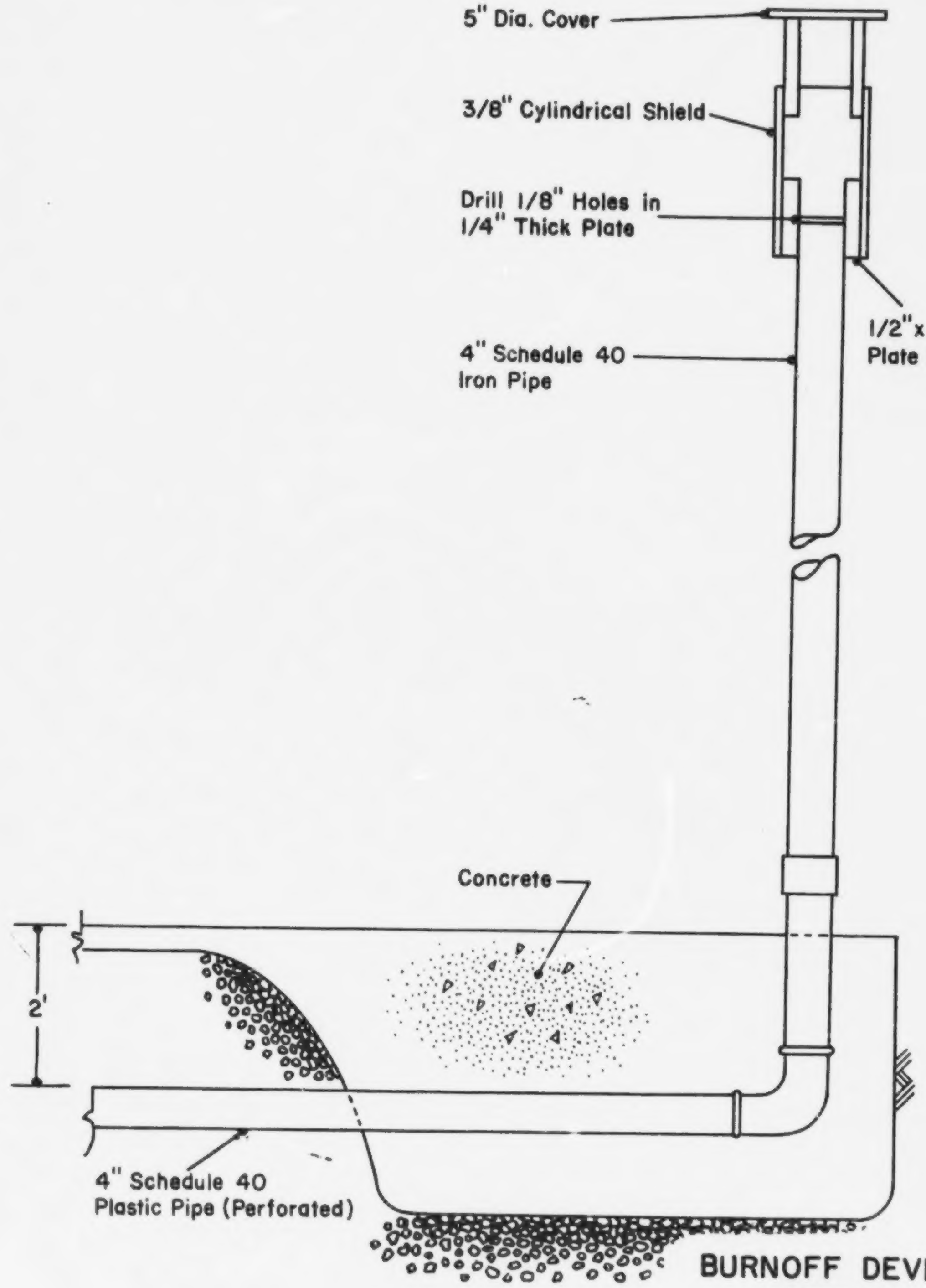


SCALE 1" = 300'
LEGEND
Fill Limits
Probe Location ⊙
Probe in Manhole ●
New Probe ⊙T3
JUNK YARD
TRAILER PARK
TRUCK YARD
ROAD
6A
6
13C
7A
13A
13
7C
18B
2C
BURN OFF DEVICE
T1
T2
T3
T4
750 FT. LONG, 2 FT. X 6 FT., GRAVEL FILLED TRENCH
2B
8
T5
T6
VENT WELLS
14A
25
22A
8B
27
3A
19A
19B
T7
T8
STUB FOR FUTURE DEVICES
T9
15A
26
9C
3B
T10
T11
28
T12
T13
23A
10A
10
T14
16A

PLAN-CONTROL SYSTEM
NEW PROBE LOCATIONS
SITE 8

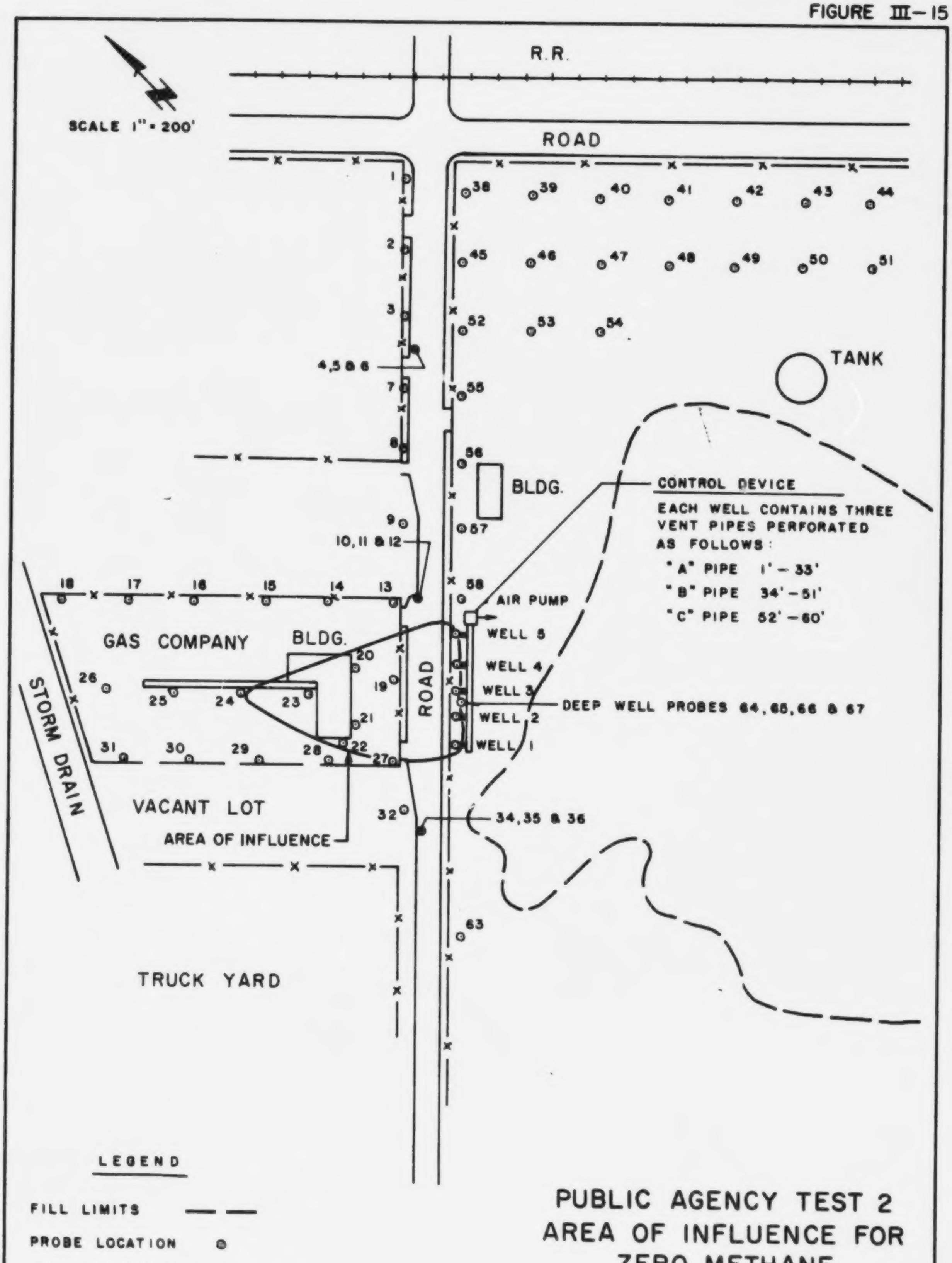

2'
Concrete Cover
2"
Cap
To Second Well
Gate Valve
To Burner
2'
6'
750' Trench
(Gravel Filled)
24" Dia.
50' Deep (Gravel Filled)

TYPICAL VENT WELL
SITE 8

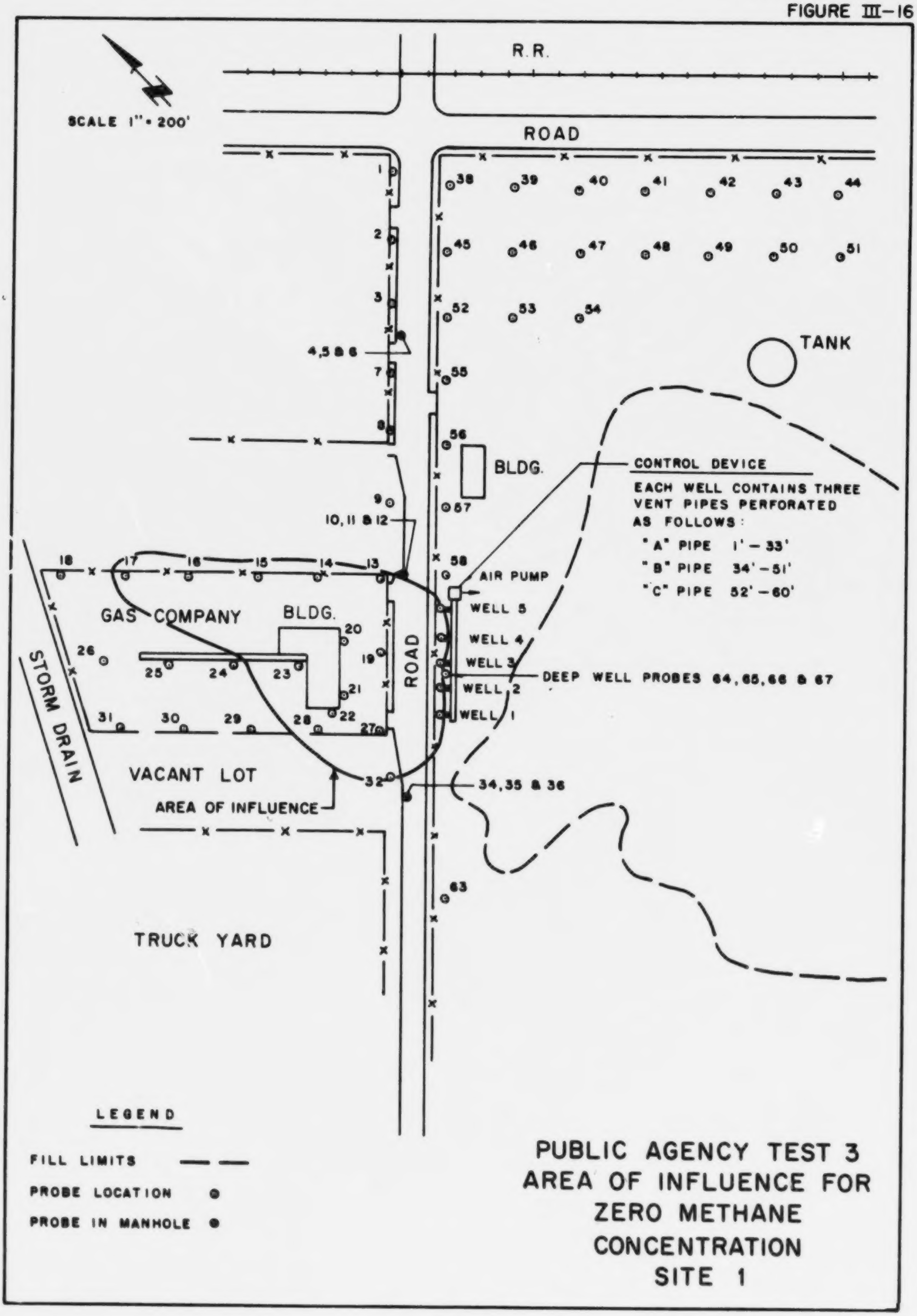

5" Dia. Cover
3/8" Cylindrical Shield
Drill 1/8" Holes in 1/4" Thick Plate
1/2" x 1" x 6" Plate (2)
4" Schedule 40 Iron Pipe
Concrete
2'
4" Schedule 40 Plastic Pipe (Perforated)

BURNOFF DEVICE
SITE 8

FIGURE III-15

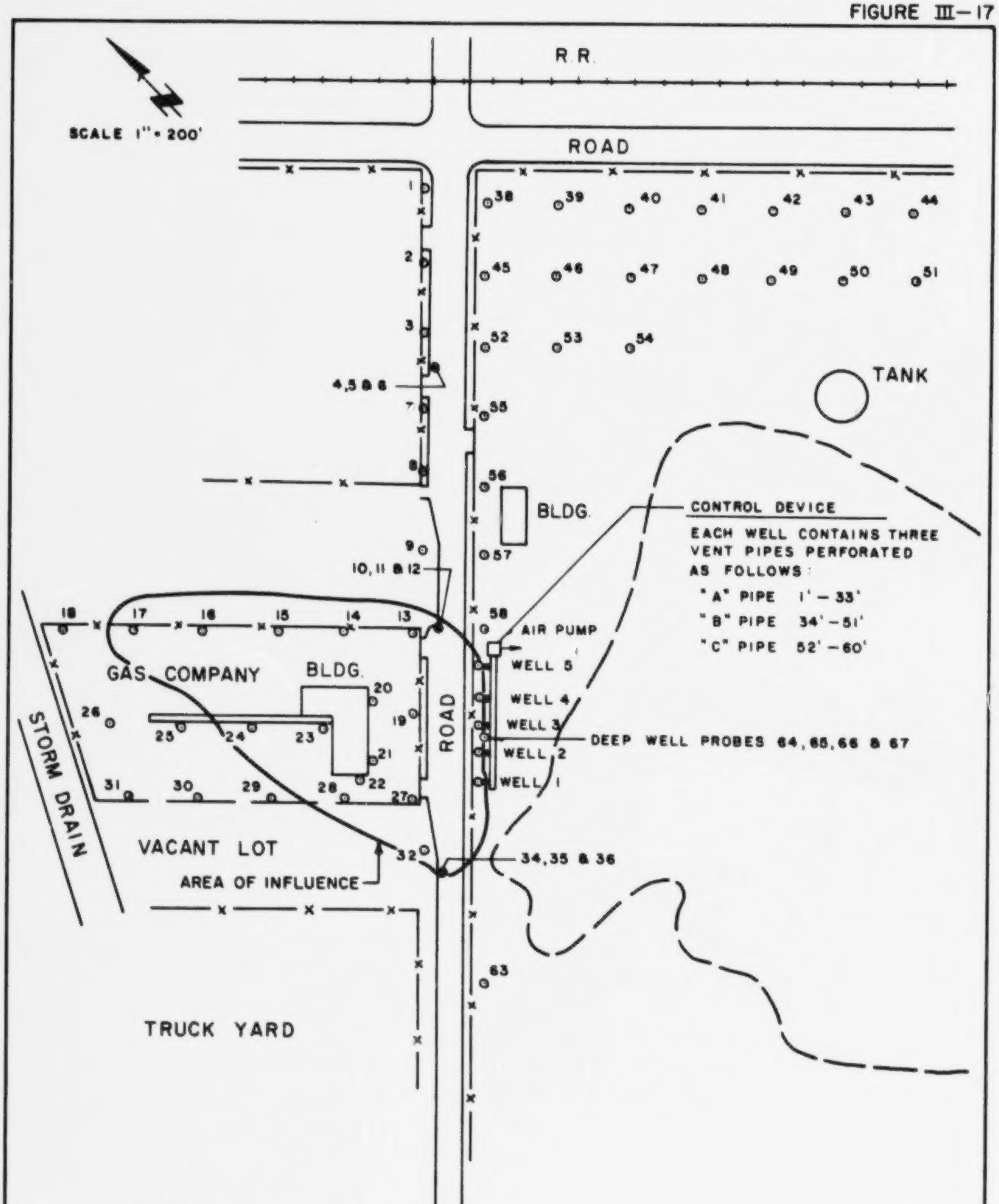

SCALE 1" = 200'
R.R.
ROAD
TANK
BLDG.
CONTROL DEVICE
EACH WELL CONTAINS THREE VENT PIPES PERFORATED AS FOLLOWS:
"A" PIPE 1' – 33'
"B" PIPE 34' – 51'
"C" PIPE 52' – 60'
AIR PUMP
WELL 5
WELL 4
WELL 3
WELL 2
WELL 1
DEEP WELL PROBES 64, 65, 66 & 67
GAS COMPANY
BLDG.
ROAD
STORM DRAIN
VACANT LOT
AREA OF INFLUENCE
34, 35 & 36
4, 5 & 6
10, 11 & 12
TRUCK YARD
1
2
3
7
8
9
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
63
LEGEND
FILL LIMITS — —
PROBE LOCATION ⊙
PROBE IN MANHOLE ●

PUBLIC AGENCY TEST 2
AREA OF INFLUENCE FOR
ZERO METHANE
CONCENTRATION
SITE 1


SCALE 1" = 200'
R.R.
ROAD
TANK
BLDG.
CONTROL DEVICE
EACH WELL CONTAINS THREE VENT PIPES PERFORATED AS FOLLOWS:
"A" PIPE 1' – 33'
"B" PIPE 34' – 51'
"C" PIPE 52' – 60'
AIR PUMP
WELL 5
WELL 4
WELL 3
WELL 2
WELL 1
DEEP WELL PROBES 64, 65, 66 & 67
4, 5 & 6
10, 11 & 12
34, 35 & 36
GAS COMPANY
BLDG.
ROAD
STORM DRAIN
VACANT LOT
AREA OF INFLUENCE
TRUCK YARD
1
2
3
7
8
9
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
63
LEGEND
FILL LIMITS — —
PROBE LOCATION ○
PROBE IN MANHOLE ●

PUBLIC AGENCY TEST 3
AREA OF INFLUENCE FOR
ZERO METHANE
CONCENTRATION
SITE 1

FIGURE III-17


R.R.
SCALE 1" = 200'
ROAD
1
2
3
4,5 & 6
7
8
9
10, 11 & 12
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
TANK
BLDG.
CONTROL DEVICE
EACH WELL CONTAINS THREE VENT PIPES PERFORATED AS FOLLOWS:
"A" PIPE 1' – 33'
"B" PIPE 34' – 51'
"C" PIPE 52' – 60'
AIR PUMP
WELL 5
WELL 4
WELL 3
WELL 2
WELL 1
DEEP WELL PROBES 64, 65, 66 & 67
18
17
16
15
14
13
GAS COMPANY
BLDG.
20
19
21
22
26
25
24
23
31
30
29
28
27
ROAD
STORM DRAIN
VACANT LOT
32
34, 35 & 36
AREA OF INFLUENCE
63
TRUCK YARD

LEGEND

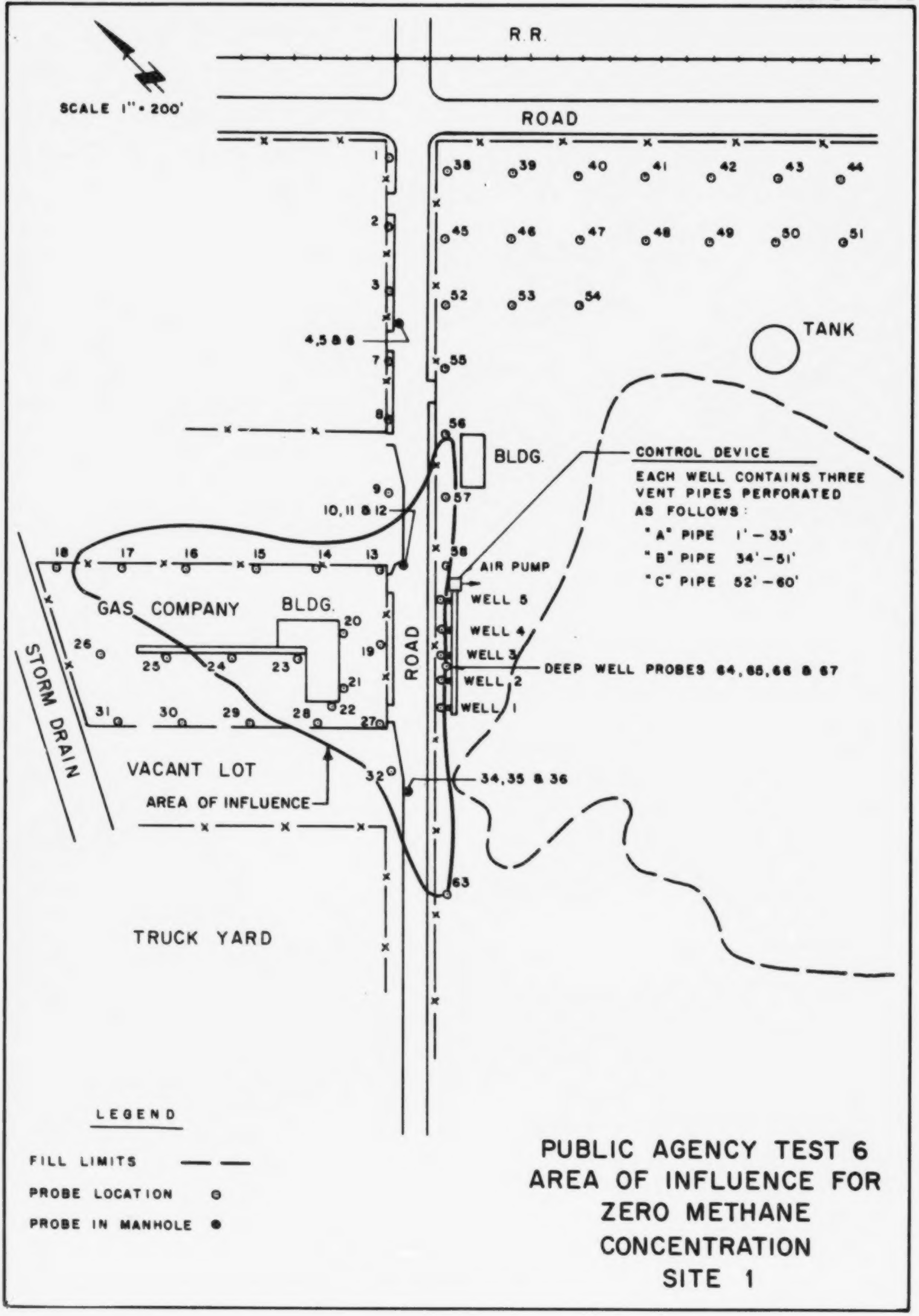
FILL LIMITS — —

PROBE LOCATION ○

PROBE IN MANHOLE ●

PUBLIC AGENCY TEST 5
AREA OF INFLUENCE FOR ZERO METHANE CONCENTRATION
SITE 1

FIGURE III-18


R.R.
ROAD
SCALE 1" = 200'
1
2
3
4,5 & 6
7
8
9
10, 11 & 12
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
TANK
BLDG.
CONTROL DEVICE
EACH WELL CONTAINS THREE VENT PIPES PERFORATED AS FOLLOWS:
"A" PIPE 1' – 33'
"B" PIPE 34' – 51'
"C" PIPE 52' – 60'
AIR PUMP
WELL 5
WELL 4
WELL 3
WELL 2
WELL 1
DEEP WELL PROBES 64, 65, 66 & 67
18
17
16
15
14
13
GAS COMPANY
BLDG.
20
19
26
25
24
23
21
22
ROAD
STORM DRAIN
31
30
29
28
27
VACANT LOT
32
34, 35 & 36
AREA OF INFLUENCE
63
TRUCK YARD
LEGEND
FILL LIMITS
PROBE LOCATION
PROBE IN MANHOLE

PUBLIC AGENCY TEST 6
AREA OF INFLUENCE FOR
ZERO METHANE
CONCENTRATION
SITE 1

FIGURE III-19

METHANE CONCENTRATION, PROBE 19, 10 DECEMBER 1968
SITE 1

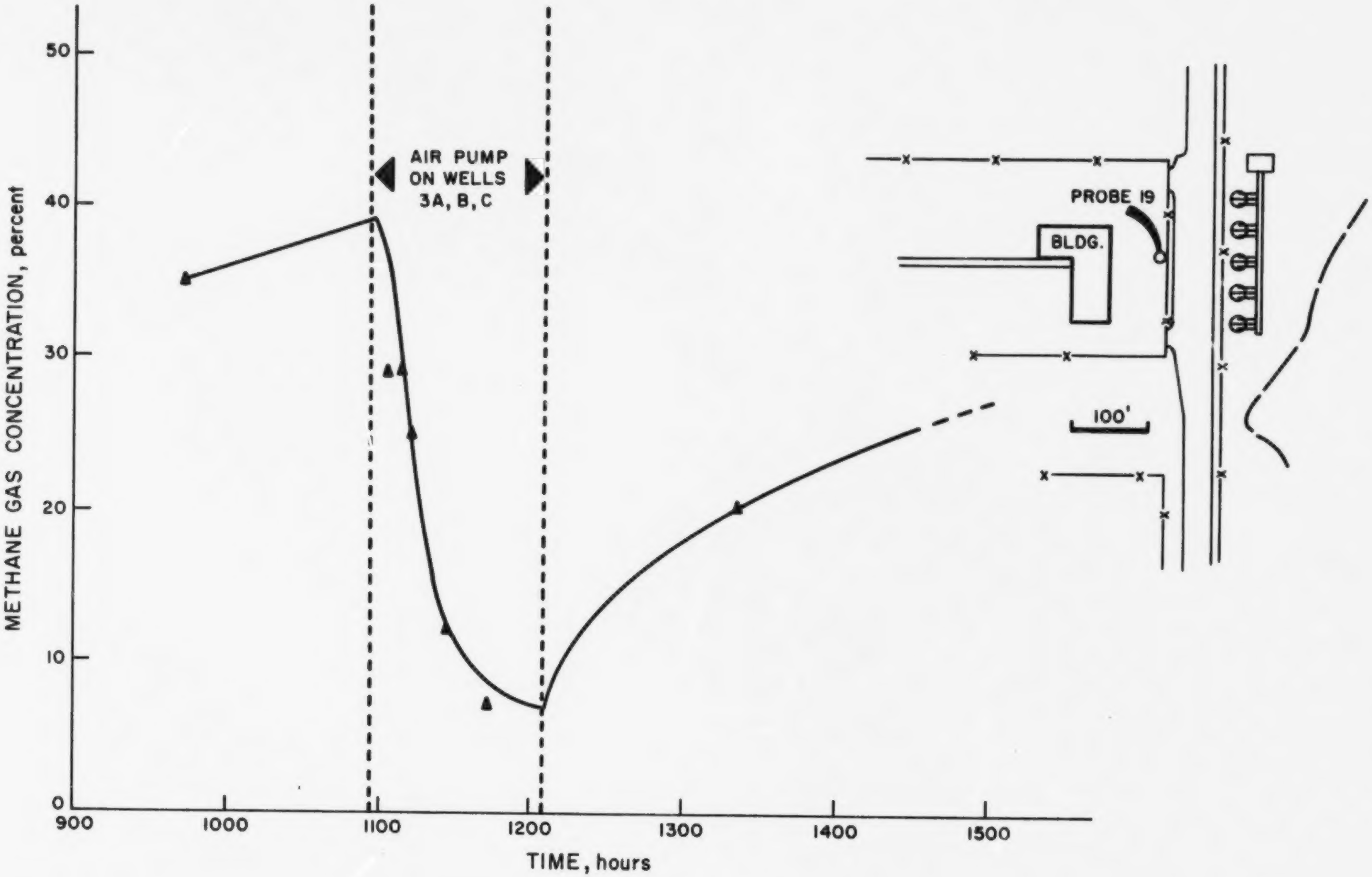
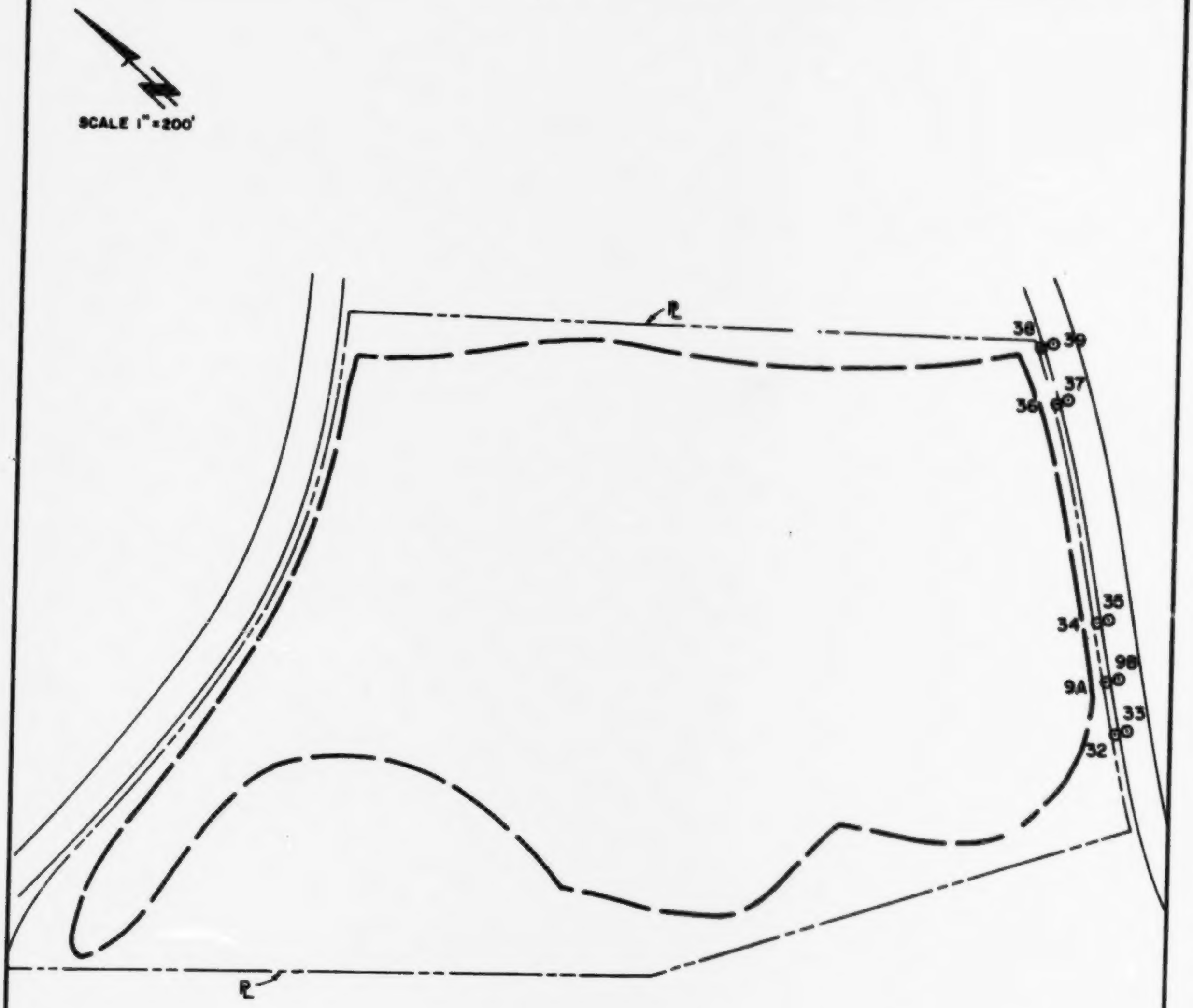


FIGURE III-20


SCALE 1"=200'
℄
38
39
37
36
35
34
9B
9A
33
32
℄

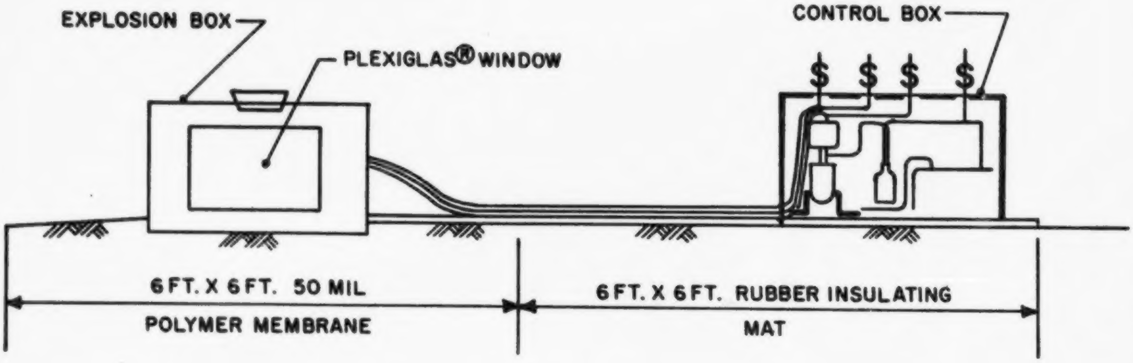
LEGEND

Fill Limits — —

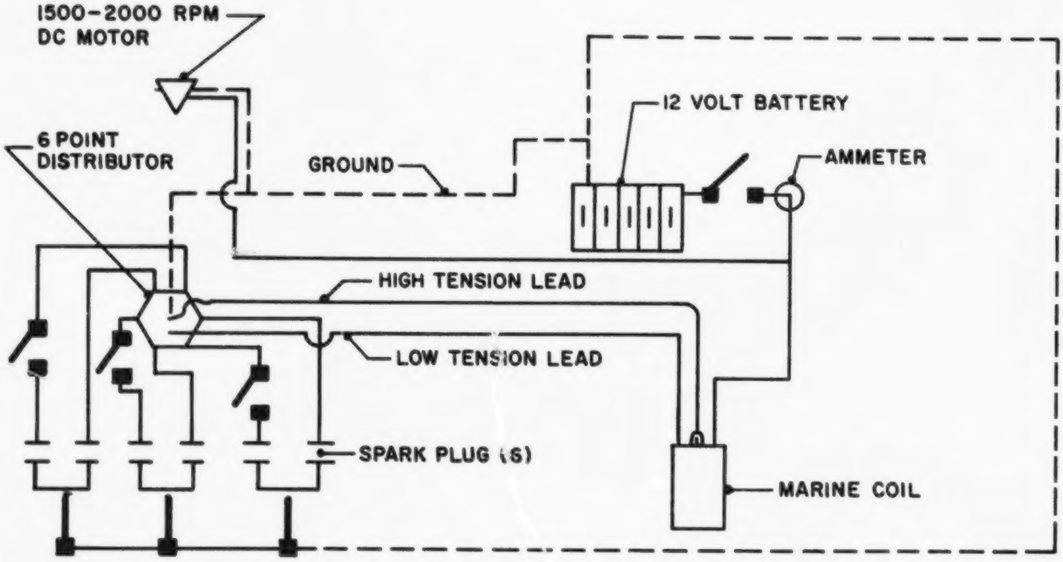
Probe Location ⊙

NEW TRENCH PROBES
SITE 5

FIGURE III-21


EXPLOSION BOX
PLEXIGLAS® WINDOW
CONTROL BOX
6 FT. X 6 FT. 50 MIL
POLYMER MEMBRANE
6 FT. X 6 FT. RUBBER INSULATING
MAT

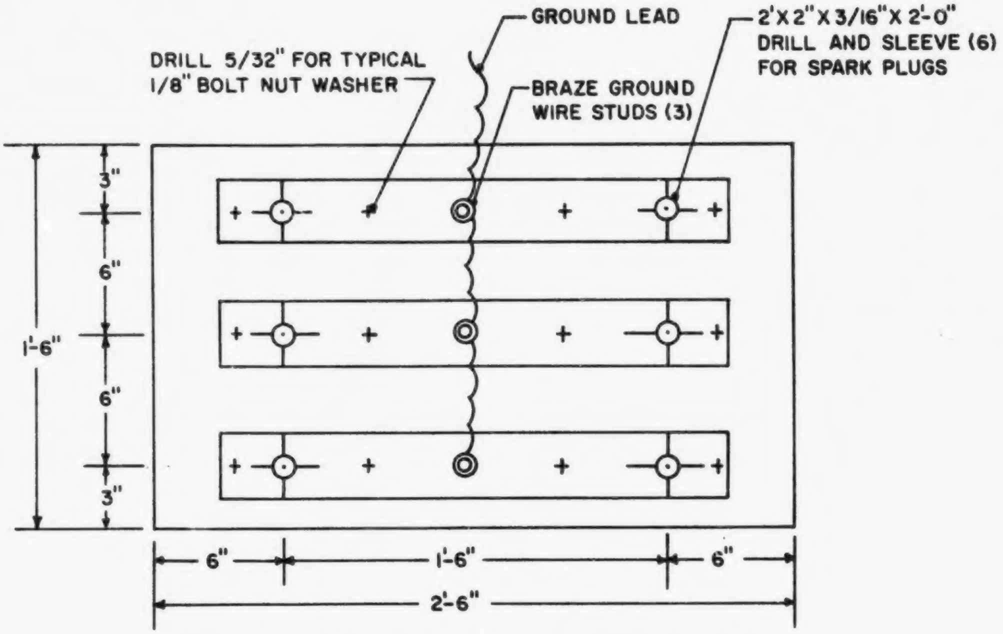
SET UP


1500-2000 RPM
DC MOTOR
6 POINT
DISTRIBUTOR
GROUND
12 VOLT BATTERY
AMMETER
HIGH TENSION LEAD
LOW TENSION LEAD
SPARK PLUG (S)
MARINE COIL

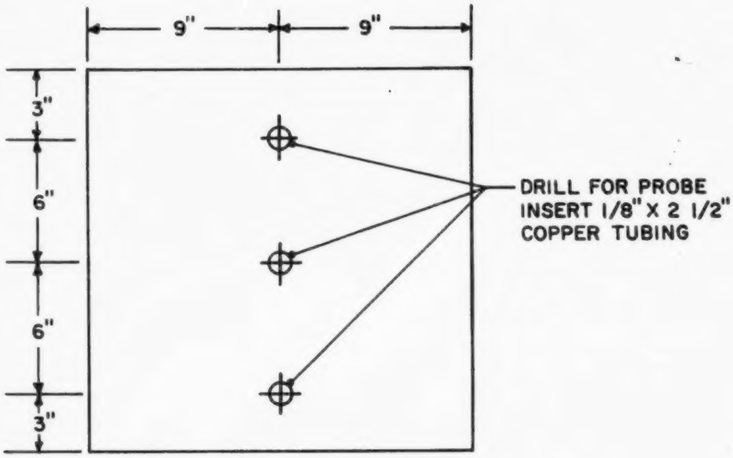
WIRING

EXPLOSION UNIT
SCHEMATIC

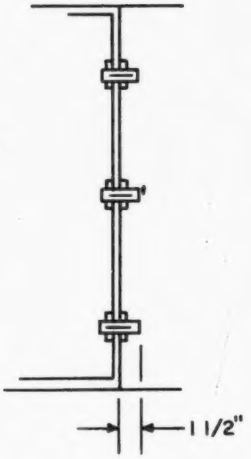
FIGURE III-22


GROUND LEAD
2'X 2" X 3/16" X 2'-0"
DRILL AND SLEEVE (6)
FOR SPARK PLUGS
DRILL 5/32" FOR TYPICAL
1/8" BOLT NUT WASHER
BRAZE GROUND
WIRE STUDS (3)
3"
6"
1'-6"
6"
3"
6"
1'-6"
6"
2'-6"

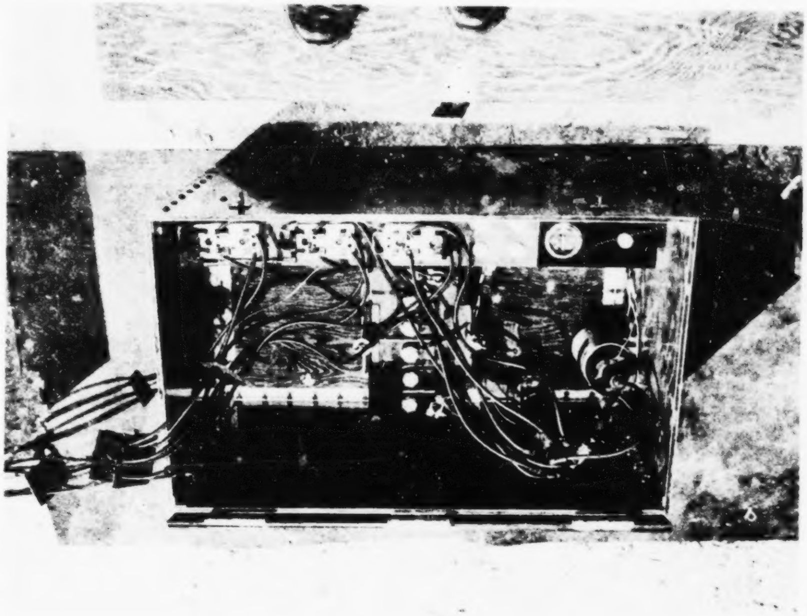
BACK WALL OUTSIDE


9"
9"
3"
6"
6"
3"
DRILL FOR PROBE
INSERT 1/8" X 2 1/2"
COPPER TUBING

RIGHT SIDE WALL



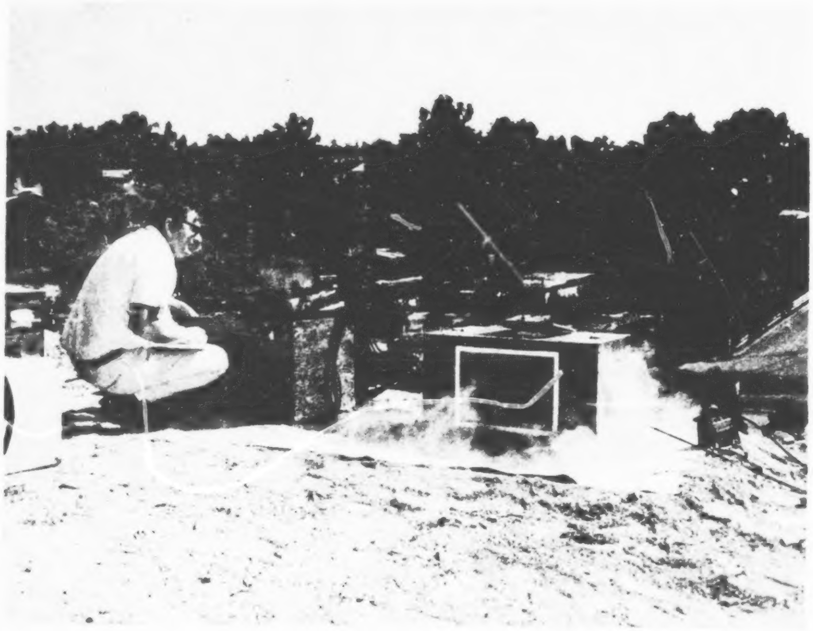
EXPLOSION BOX
DETAILS



UNIT CONTROL AND INSULATING MAT

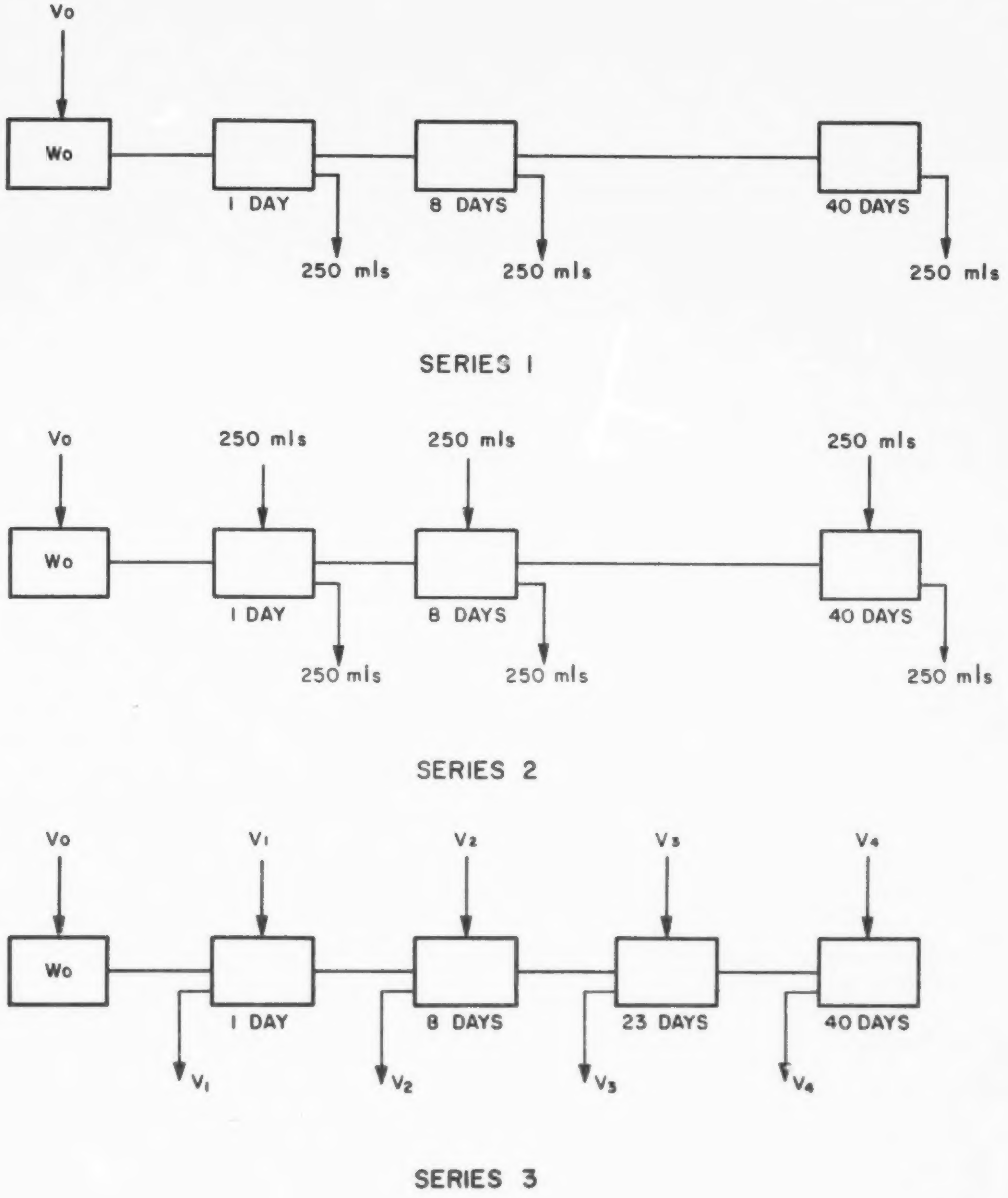
EXPLOSION BOX AND BARRIER MEMBRANE

GAS EXPLOSION UNIT
COMPONENTS



GAS EXPLOSION UNIT
DETONATION AT
SITE 5

FIGURE IV-1


Vo
Wo
1 DAY
8 DAYS
40 DAYS
250 mls
250 mls
250 mls
SERIES 1
Vo
250 mls
250 mls
250 mls
Wo
1 DAY
8 DAYS
40 DAYS
250 mls
250 mls
250 mls
SERIES 2
Vo
V1
V2
V3
V4
Wo
1 DAY
8 DAYS
23 DAYS
40 DAYS
V1
V2
V3
V4
SERIES 3

ADOPTED EXPERIMENTAL
LEACHING SYSTEMS

FIGURE IV-2

HYPOTHETICAL VARIATION OF RELEASED COD AND TDS IN SOLUTION FROM DECOMPOSING REFUSE

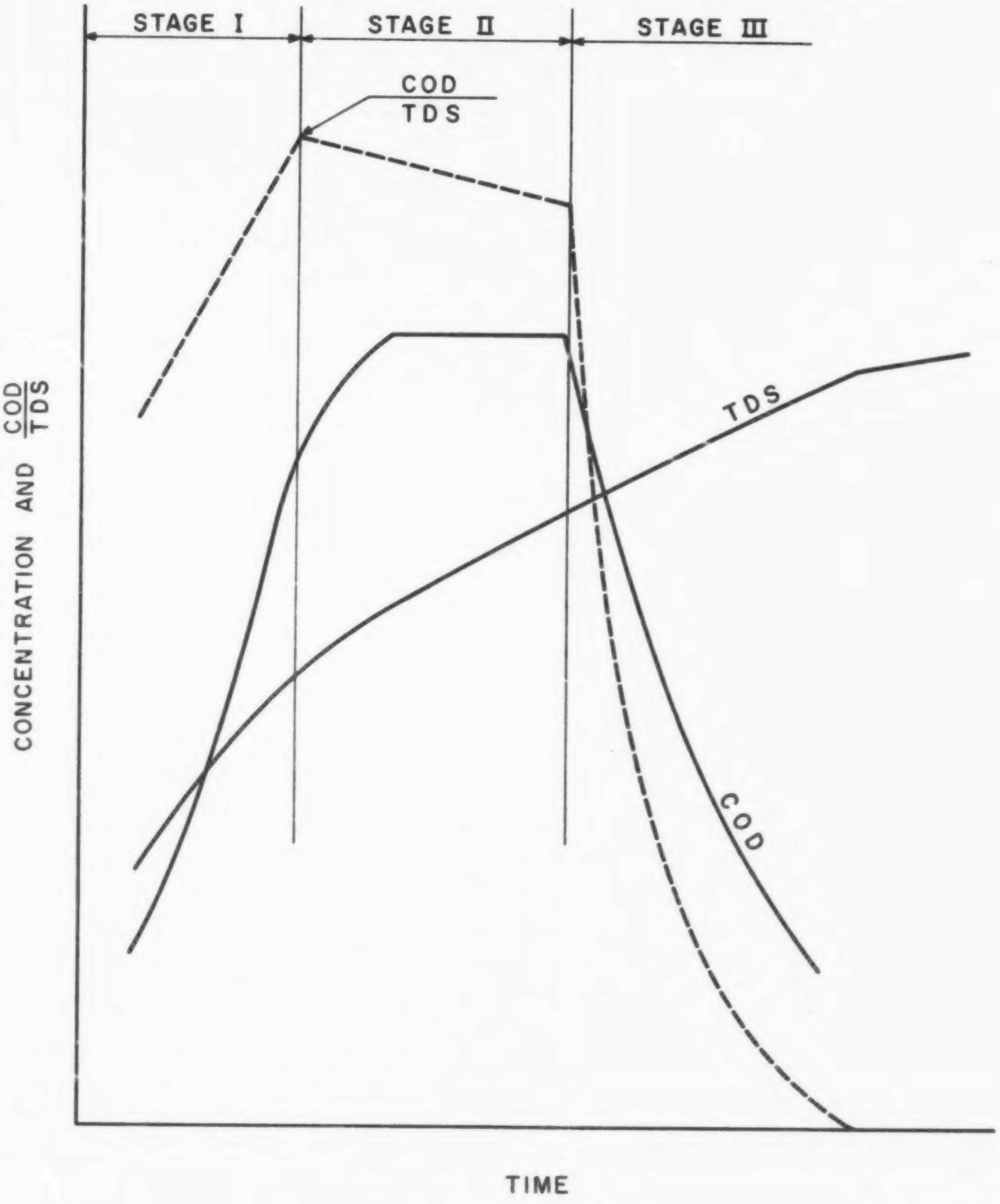
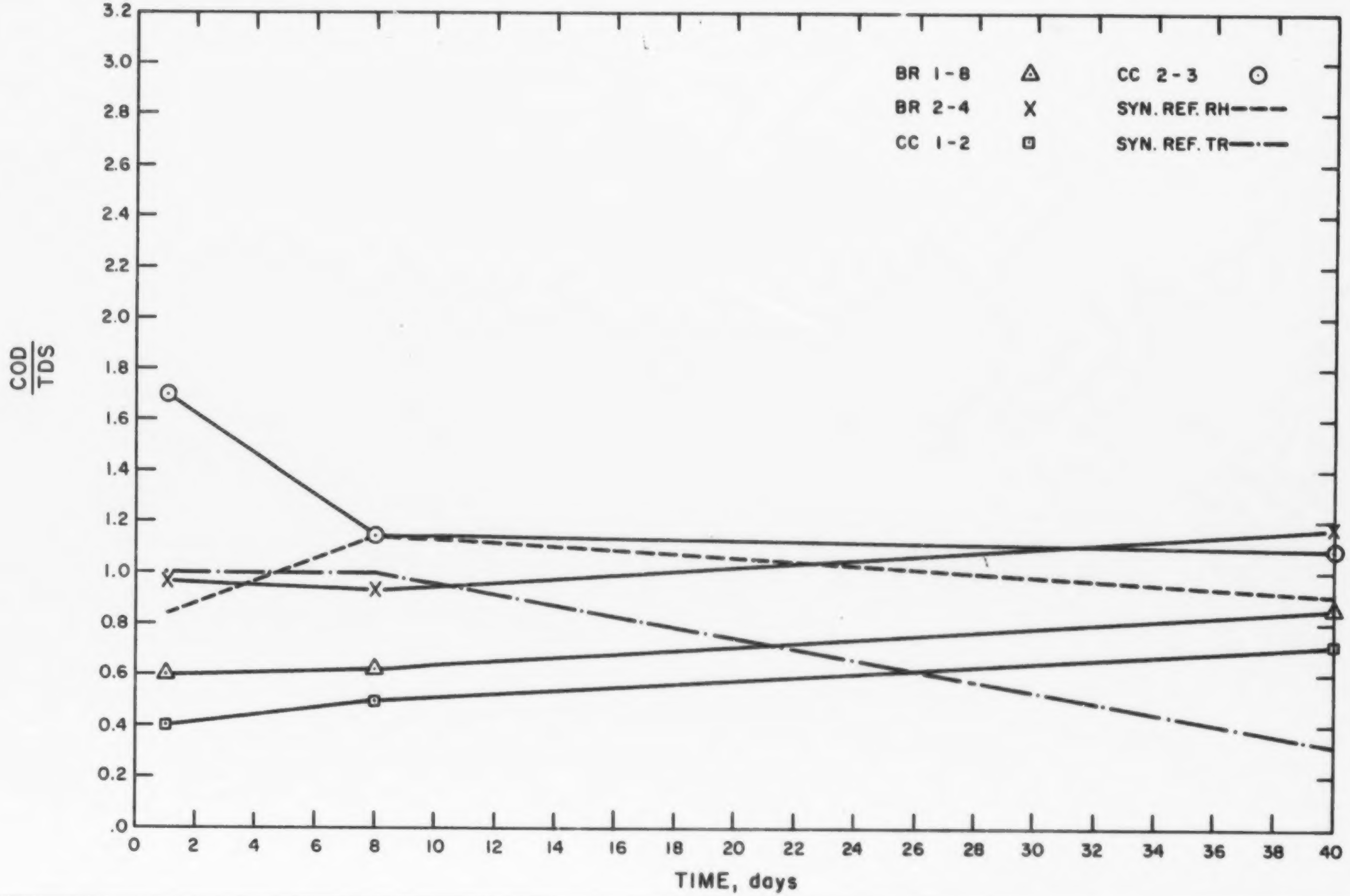
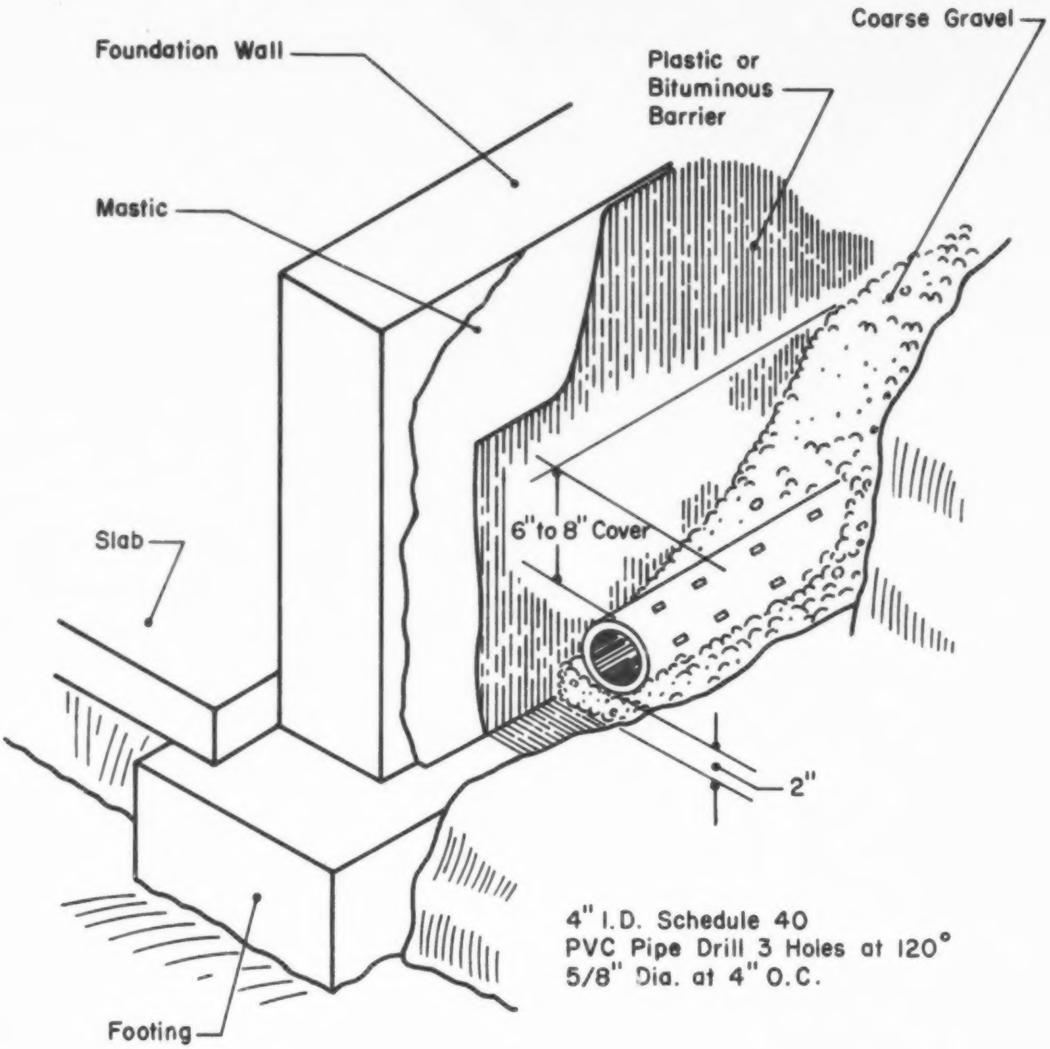


FIGURE IV-3

VARIATION OF COD/TDS RATIOS IN SERIES 1



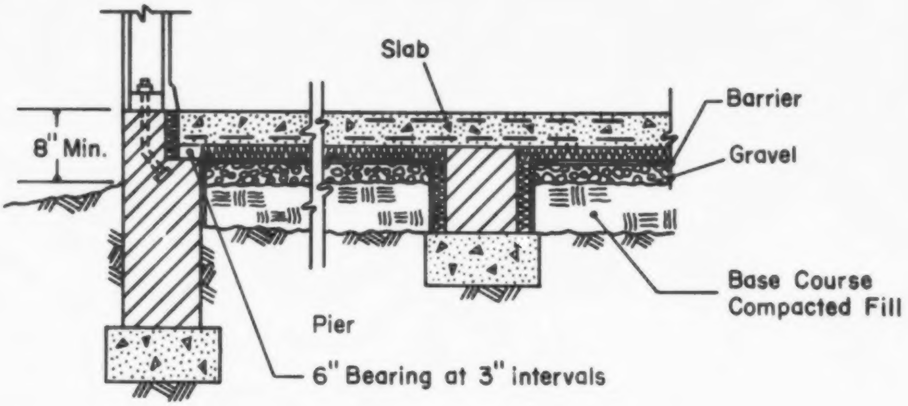

Foundation Wall
Mastic
Plastic or Bituminous Barrier
Coarse Gravel
Slab
6" to 8" Cover
2"
Footing

4" I.D. Schedule 40
PVC Pipe Drill 3 Holes at 120°
5/8" Dia. at 4" O.C.

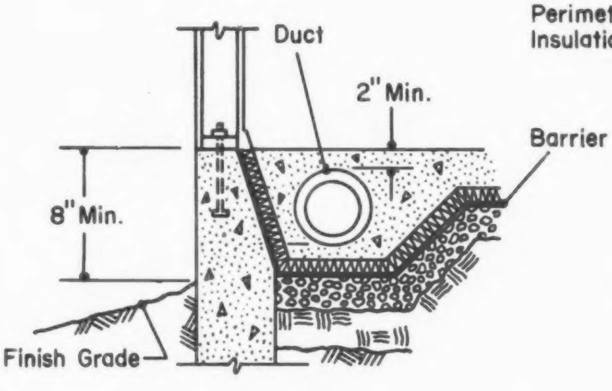
Vent outside the building to ten feet above grade or 2 feet above building if within 10 feet of building.

DESIGN EXAMPLE
FOUNDATION VENT

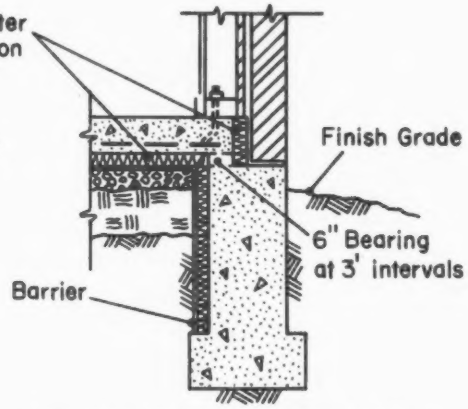
FIGURE VIII-2


Slab
Barrier
8" Min.
Gravel
Base Course
Compacted Fill
Pier
6" Bearing at 3" intervals

FRAME WALL CONSTRUCTION

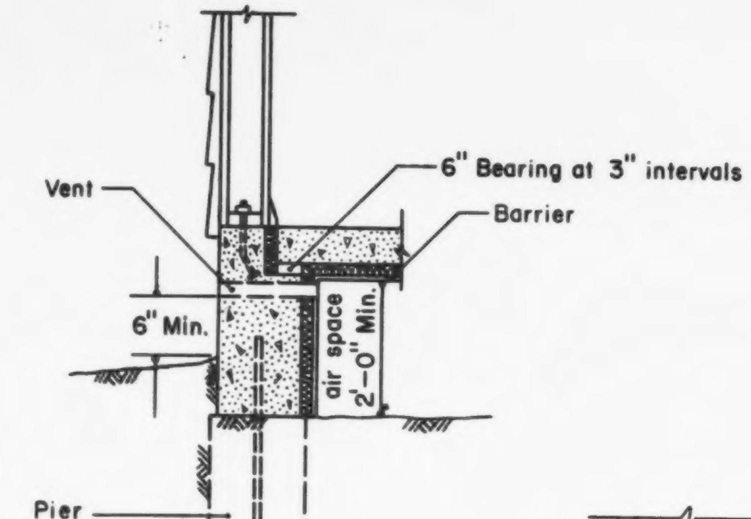

Duct
2" Min.
Barrier
8" Min.
Finish Grade

WITH DUCT IN SLAB

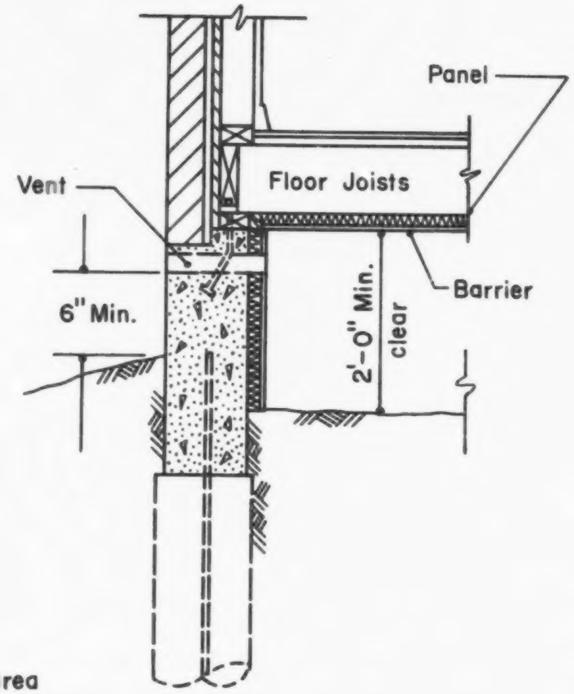

Perimeter
Insulation
Finish Grade
6" Bearing
at 3' intervals
Barrier

VENEER WALL CONSTRUCTION

DESIGN EXAMPLE
BARRIERS UNDER SLABS


6" Bearing at 3" intervals
Vent
Barrier
6" Min.
air space
2'-0" Min.
Pier
(Optional)

STRUCTURAL SLAB FLOOR

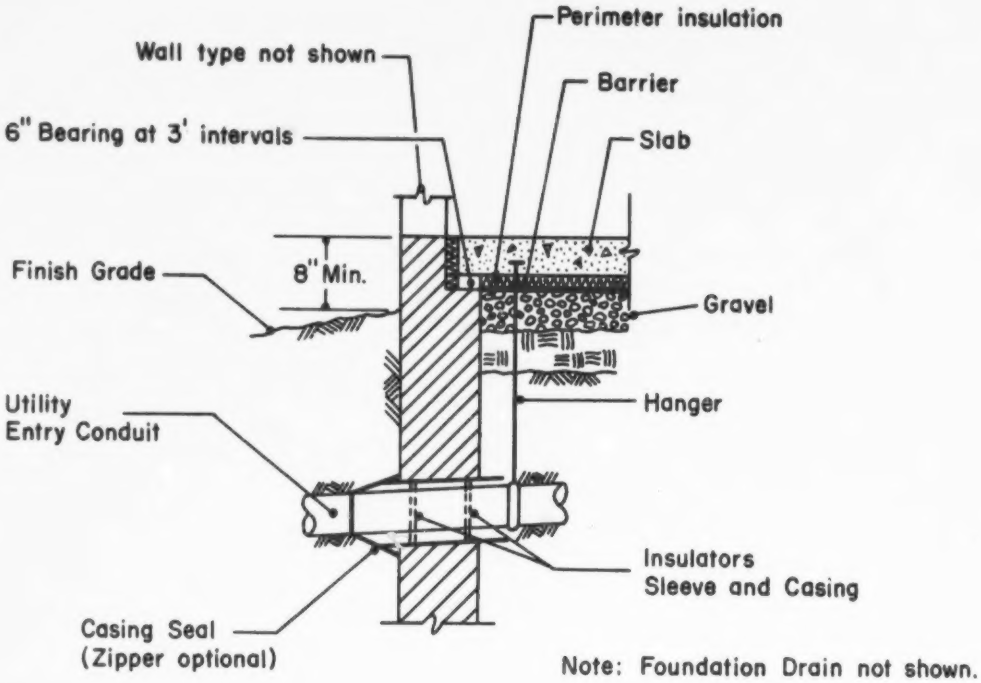

Panel
Floor Joists
Vent
Barrier
6" Min.
2'-0" Min.
clear

Note: Vent area to be 4% of Floor area or install mechanical blowers under the floor.

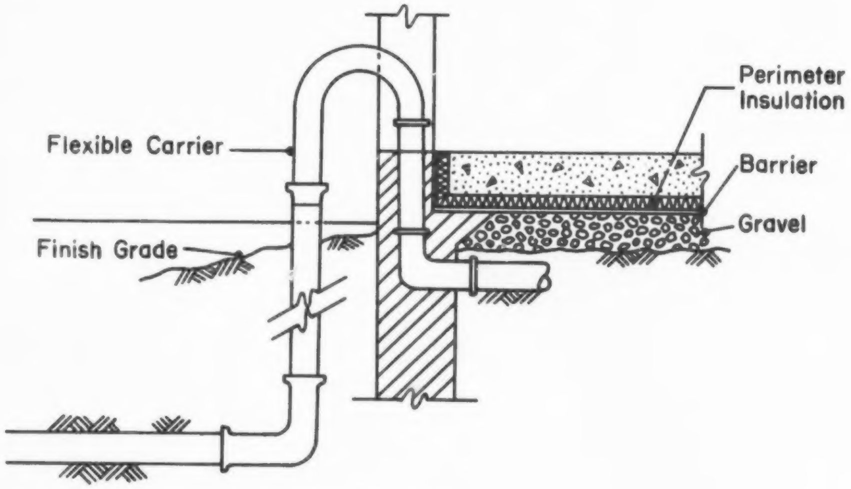
WOOD FRAME FLOOR

DESIGN EXAMPLE
UNDERFLOOR VENTS

FIGURE VIII-4


Perimeter insulation
Wall type not shown
Barrier
6" Bearing at 3' intervals
Slab
Finish Grade
8" Min.
Gravel
Hanger
Utility
Entry Conduit
Insulators
Sleeve and Casing
Casing Seal
(Zipper optional)
Note: Foundation Drain not shown.

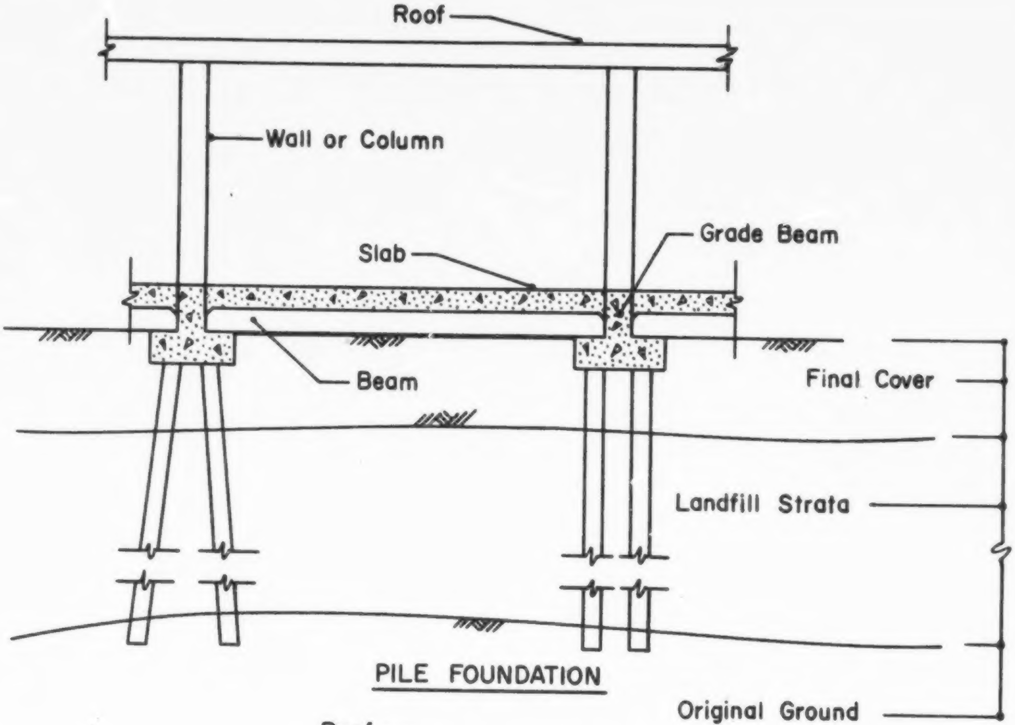
SLEEVED ENTRY


Perimeter
Insulation
Flexible Carrier
Barrier
Gravel
Finish Grade

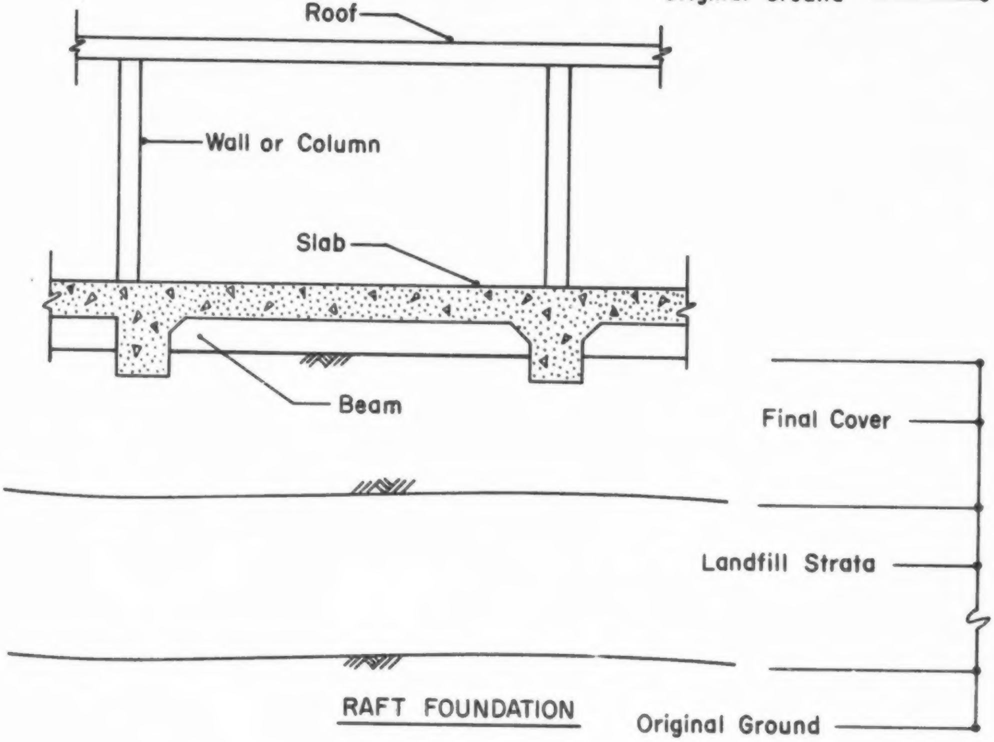
FLEXIBLE ENTRY

DESIGN EXAMPLE
ENTRY CONDUITS

FIGURE VIII-5

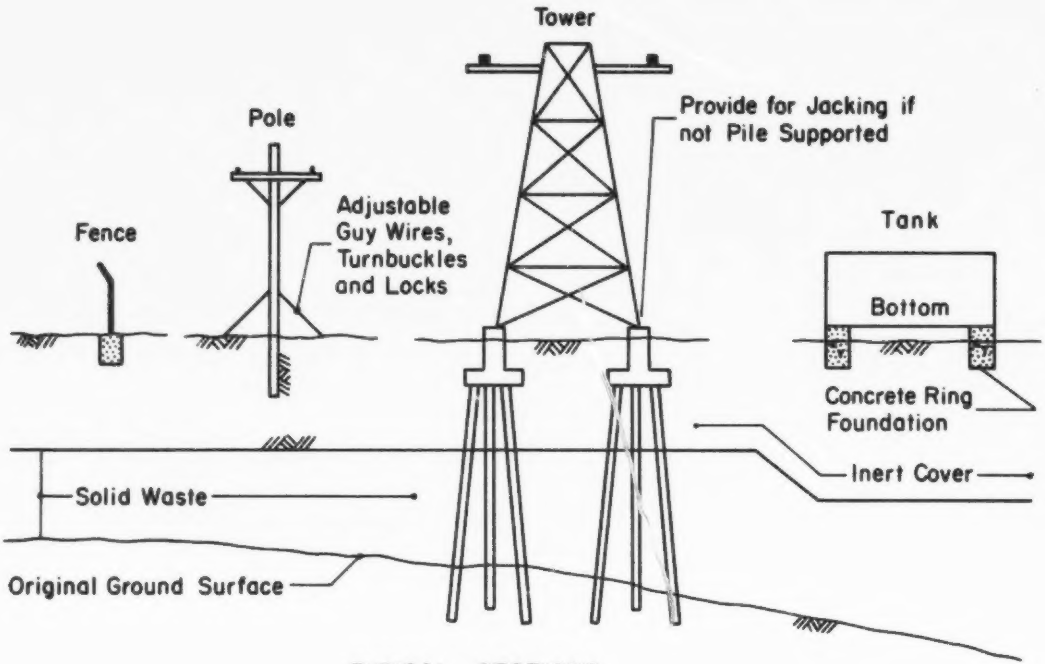

Roof
Wall or Column
Slab
Grade Beam
Beam
Final Cover
Landfill Strata
Original Ground

PILE FOUNDATION


Roof
Wall or Column
Slab
Beam
Final Cover
Landfill Strata
Original Ground

RAFT FOUNDATION

DESIGN EXAMPLE FOOTINGS


Tower
Pole
Provide for Jacking if not Pile Supported
Adjustable Guy Wires, Turnbuckles and Locks
Fence
Tank
Bottom
Concrete Ring Foundation
Inert Cover
Solid Waste
Original Ground Surface

TYPICAL SECTIONS

DESIGN LOADS

As required by Use or Codes.

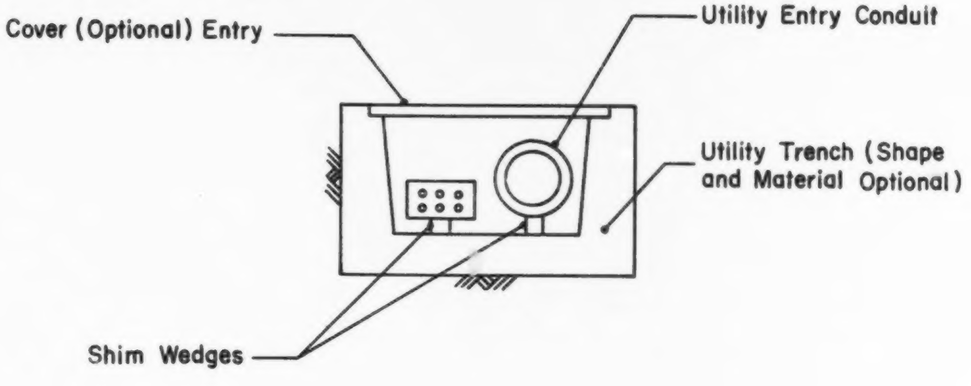
DESIGN

Major structures or heavily loaded structures should be on Piles. Minor structures or light loads may be placed on compacted fill as determined by a Soils Engineer. Settlement Criteria to be determined for each structure individually depending on Use and Type of structure.

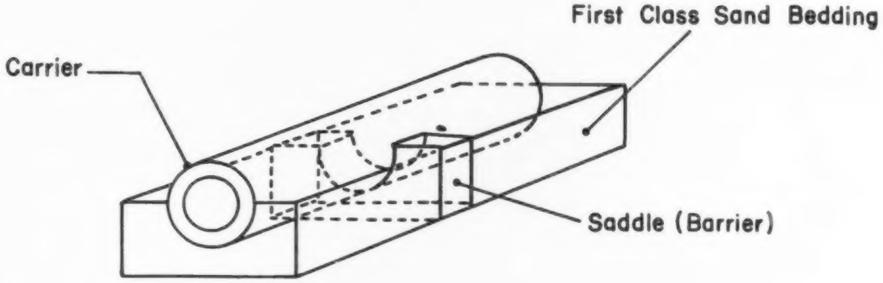
DESIGN PROCEDURES

Design Foundation for specific conditions with special attention to future settlement.

DESIGN EXAMPLE
STRUCTURES
OTHER THAN
BUILDINGS


Cover (Optional) Entry
Utility Entry Conduit
Utility Trench (Shape and Material Optional)
Shim Wedges

UTILITY TRENCH


First Class Sand Bedding
Carrier
Saddle (Barrier)

COMBINATION GAS BARRIER PIPE SADDLE

DESIGN EXAMPLE UTILITY BEDDING

APPENDIX G

SANITARY LANDFILL STANDARD SPECIFICATIONS FOR GOOD PRACTICE

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PREFACE

For years man has disposed of much of his waste materials by placing it on the land. As his knowledge grew and heavy equipment became available, disposal techniques slowly changed. The present method of sanitary landfilling finally evolved. However, in some areas, improperly operated and maintained completed dump sites are a blight on the land.

The primary goal of the following pages is to utilize sound engineering principles to establish guidelines, standards and specifications leading to an improved method of landfilling with a thought toward future site utilization, i.e., planning for the "ultimate use" of the completed site before commencing the waste disposal operations. This concept in practice can truly become a land reclamation process not only providing space for waste disposal, but restoring steep canyons and other marginal lands to usable sites.

This Appendix G, "Sanitary Landfill Standard Specifications For Good Practice" is separated into four parts: Model Ordinance For The Control of Sanitary Landfills; Uniform Standards For Location, Design, Construction, and Maintenance of Sanitary Landfills Subject to Sanitary Landfill Code; Suggested Addenda to Building Codes Re: Design and Construction of Structural Improvements on and Immediately Adjacent to Sanitary Landfills; and Suggested Addenda to Local Engineering Regulations Re: Design and Construction of Surface and Subsurface Improvements.

The initial draft of these four sections was inclusively entitled "Model Sanitary Landfill Code." As such, it was reviewed by a "Code Review Committee" consisting of representatives of the following governmental agencies and private enterprises: Universal By-Products, Inc.; Los Angeles By-Products Company; Office of Solid Waste Management Programs, Environmental Protection Agency; California Department of Public Health; California Department of Water Resources; Orange County Road Department; Los Angeles County Sanitation Districts; Los Angeles County Health Department; Los Angeles County Regional Planning Commission; City of Los Angeles Department of Public Works; and City of Los Angeles Department of Building and Safety.

The committee met and drafted written comments. These comments were reviewed, resulting in changing the format to present the information as four separate documents which may be codified at more than one level of detail.

The first document, "Model Ordinance for the Control of Sanitary Landfills," is designed as a Sanitary Landfill Code to be adopted by communities who do not have adequate legislation to control public and private landfilling practices. The ordinance contains only provisions which would not require regular amending. It does have an enabling section, Sec. 201 b., which authorizes the Administrative Officer to write, revise, revoke, and enforce additional rules and regulations (the second document) which may be subject to change, but are necessary for the prevention of nuisances or hazards to public health and safety.

It is anticipated that any community before adopting the "Model Ordinance" will review it and make any necessary changes to tailor it to their individual needs. This ordinance does not prohibit other types of landfilling or indiscriminate dumping, so a community that adopts this ordinance may wish to adopt additional measures to prohibit those activities. An adopting agency will also have to determine what position or individual should be appointed to serve as the Administrative Officer, what type of individuals should be appointed to serve on the Board of Appeals, etc.

The responsibilities of the Administrative Officer will involve numerous technically complex decisions for successful implementation of the regulations. He should therefore be either a registered or licensed engineer, or an administrator, such as a city manager with technical competence provided by his staff or consultants.

The responsibilities of the Board of Appeals will also require its members to make technically complex decisions. Therefore, they should be qualified by experience and training to pass upon matters pertaining to the provisions and objectives of the "Model Ordinance." The size of the adopting community may have a direct bearing on the number and type of qualified individuals available to serve on the Board of Appeals.

The second document, "Uniform Standards for Location, Design, Construction, and Maintenance of Sanitary Landfills Subject to Sanitary Landfill Code," contains the rules and regulations or standards for the construction and operation of sanitary landfills. The document is not intended to be a legally adopted ordinance, but can be legally enforced and revised by the Administrative Officer through an enabling provision, Sec. 201 b., in the "Model Ordinance." This provision allows the Administrative Officer to develop and enforce rules which are necessary for the prevention of nuisances or hazards to public health and safety, but may be subject to change. Rules that are subject to change should not be placed in an ordinance. Changes and revisions to ordinances are subject to the legislative process which is deliberate and sometimes slow to act.

"Uniform Standards" is not intended as a design specification or instruction manual. The provisions of the Uniform Standards are not intended to prevent the use of any sound design or practice not specifically prescribed, provided that any such alternate is approved by the Administrative Officer.

Although the "Uniform Standards" can be easily revised by the Administrative Officer, certain material and dimension limitations or requirements have not been specified, but the word "approved" has been used in lieu thereof. The "Model Ordinance" contains a definition for "approved." This normally occurs where absolute limitations or requirements can not be established. This is not meant to imply that specified dimensions are absolute. The determination of such limitations or requirements may vary from site to site depending on many factors, such as native site soil, cover material, site geology and hydrology, risk, etc. Much research is being done on these subjects in many areas of the county and it is necessary that an Administrative Officer or his staff stay abreast of new developments.

The third and fourth documents, "Suggested Addenda to Building Codes Re: Design and Construction of Structural Improvements On, and Immediately Adjacent to Sanitary Landfills" and "Suggested Addenda to

Local Engineering Regulations Re: Design and Construction of Surface and Subsurface Improvements," are designed for input into existing building codes or public works specifications of communities that have such a need. It is emphasized that these documents are not a part of the "Model Ordinance" or "Uniform Standards."

MODEL ORDINANCE FOR CONTROL OF SANITARY LANDFILLS

CHAPTER 1. TITLE AND SCOPE

Sec. 101 Title

This ordinance shall be known as the "Sanitary Landfill Code," and may be cited as such.

Sec. 102 Purpose

The purpose of this Code is to provide for the administration and enforcement of minimum standards to prevent nuisances and to safeguard life or limb, health, property, and public welfare from sanitary landfilling operations and any effects resulting therefrom.

Sec. 103 Scope

The provisions of this Code shall apply to: (1) administration and enforcement procedures for the location, design, construction, operation, and maintenance of Sanitary Landfills; (2) issuance of permits, and the collection of all fees therefor; (3) checking plans; (4) initial and regular inspection; (5) making record plans of the facilities provided hereunder; (6) administrative procedures for implementation and enforcement of this ordinance; and (7) providing penalties for violation thereof.

In interpreting and applying the provisions of this Code, they shall be deemed to be the minimum requirements for the promotion of the public health, safety, comfort, convenience, and general welfare.

CHAPTER 2. ORGANIZATION

Sec. 201 Administrative Officer

a. General. The Administrative Officer hereby is authorized and directed to enforce all of the provisions of this Code.

b. Rules and Regulations. The Administrative Officer hereby is authorized and directed to write, revise, revoke, and enforce other rules and regulations for the design, construction, operation, and maintenance of Sanitary Landfills in addition to the provisions of this Code, whether of general or specific application, that are deemed necessary for the prevention of nuisances or hazards to public health and safety. Those rules and regulations shall be known as the "Uniform Standards For Location, Design, Construction, And Maintenance of Sanitary Landfills Subject To Sanitary Landfill Code" and be referred to herein as the "Uniform Standards."

The Administrative Officer is also authorized and directed to enforce any and all other rules and regulations in addition to the provisions of this Code, whether of general or specific application that are deemed necessary for the administration and enforcement of this Code.

c. Deputies. The Administrative Officer may deputize such officers, assistants, inspectors and employees as may be necessary to carry out the functions of the Administrative Officer, in accordance with the procedure and with the approval of the Adopting Agency.

Sec. 202 Board of Appeals

In order to determine the suitability of alternate materials and methods and to provide for the reasonable application of the provisions of this Code, including but not limited to the processing of appeals, there hereby is created a Board of Appeals, consisting of five (5) members who are qualified by experience and training to pass upon matters pertaining to the provisions and objectives of this Code. The Administrative Officer shall be an ex-officio member and shall act as secretary of the Board. The Board of Appeals shall be appointed by the Adopting Agency, and shall hold office at its pleasure. The Board of Appeals shall adopt reasonable rules and regulations for conducting its investigations and shall render all decisions and findings in writing to the Administrative Officer, with a duplicate copy to the appellant, and may recommend to the Adopting Agency such new legislation as is consistent therewith.

Sec. 203 Severability

If any provision, section, subsection, sentence, clause or phrase of this Code, or the application thereof to any person or circumstance, is held invalid or unconstitutional by the decision of any court of competent jurisdiction, such a decision shall not affect the validity and the application of the remaining portions of this Code to other persons or circumstances.

Sec. 204 Violations and Penalties

Any person, firm, or corporation violating any of the provisions of this Code shall be deemed guilty of a misdemeanor, and each such person shall be deemed guilty of a separate offense for each and every day or portion thereof during which any violation of the provisions of this Code is committed, continued, or permitted, and upon conviction of any such violation such person shall be punishable by a fine of not more than $500.00, or by imprisonment for not more than six months, or by both such fine and imprisonment.

CHAPTER 3. DEFINITIONS

Sec. 301 General

For the purposes of this Code, the terms defined in this chapter shall have the meaning stated therein.

Sec. 302 Terms

Active Material. Any biodegradable material or wholly or partially water soluble material within a Sanitary Landfill.

Administrative Officer. The individual official, board, department, or agency established and authorized by the Adopting Agency to administer and enforce the provisions of this Code.

Adopting Agency. The county, city or other governmental agency which adopts the provisions of this Code pursuant to its Legislative powers.

Applicant. Any person, corporation, firm, governmental agency, or other entity filing a preliminary application or application for permit under the provisions of this Code.

Approved. Accepted by the Administrative Officer or the Board of Appeals as complying with an application specification stated or cited in this Code, or as otherwise found suitable for the proposed use.

Approved Soil Testing Agency. An approved agency regularly engaged in the testing of soils under the direction of a Soils Engineer.

Benchmark. A mark affixed to a permanent object to furnish a datum for vertical survey control.

Board of Appeals. That Board appointed by the Adopting Agency to carry out the powers and duties of the Board of Appeals as provided herein.

Building. Any structure built for the shelter or enclosure of persons, animals, or property of any kind.

Building, Existing. A building erected or one for which a valid building permit has been issued prior to the effective date of adoption of this Code.

Cell, Refuse. Compacted refuse completely enclosed by approved cover material.

Code. The provisions of this Sanitary Landfill Code and all subsequent amendments thereto.

Combustible Waste. Waste substances capable of burning, but not explosive.

Compaction. The process of achieving a denser state in a material by applications of repeated loading such as by passages with a heavy roller or a series of heavy impacts.

Cover Material. An approved soil or equivalent material which is used to cover compacted solid waste in a Sanitary Landfill and is free of large objects and material that would be conductive to vector harborage, feeding and/or breeding.

Decomposition, Aerobic. The degradation caused by oxygen supported bacteria.

Decomposition, Anaerobic. The degradation caused by bacteria not requiring oxygen.

Differential Settlement. Non-uniform settlement.

Drainage System. All the piping within public or private premises, which conveys sewage, leachate, storm water, surface runoff, or liquid wastes to a legal point of disposal, other than the mains of a public sewer system, or a public sewage-treatment or disposal plant.

Dump. For the purposes of this Code a dump is a site upon which solid waste was placed in a manner not in compliance with this Code.

Engineer. A professional Engineer in the branch of civil engineering holding a valid certificate of registration issued by the State.

Garbage. Processing, animal, fruit, or vegetable residue resulting from handling, preparation, or cooking of foods.

Gas Barrier. A natural or constructed device serving as an obstacle to the passage of gases.

Gas Control Device. A part of a gas control system altering the volume, direction, and disposal of gasses.

Gas Control System. A combination of gas control devices.

Gas Control System, Peripheral. A gas control system such as a trench around the Sanitary Landfill boundary, backfilled with gravel or granular materials, or a series of vertical wells spaced around the perimeter of the Sanitary Landfill, or a combination of trenches, vertical wells, horizontal perforated pipes, or barriers, or any combination therof or other approved system.

Gas Control System, Central. A gas control system such as a large centrally located granular core to vent Sanitary Landfill produced gases; a system of vertical wells located near the center of the Sanitary Landfill; a series of trenches located near the center of the Sanitary Landfill, or a combination of the first three with or without the addition of perforated pipe drains, or barriers, or any combination thereof or other approved system.

Gas Control System, Natural. A gas control system consisting of a selectively placed, relatively granular soil cover in comparison with the varied tightly grained natural soil.

Gas Control System, Mechanical. A gas control system such as a series of horizontal or vertical, perforated pipes, or barriers, or any combination thereof, augmented by mechanically operated exhaust blowers or electricity, designed to prevent the migration of gases between the Sanitary Landfill and the boundary at all interfaces.

Gas Control System, Combination. A gas control system with at least two of the peripheral, central, natural, mechanical, internal or external gas control systems.

Gas Control System, External. A gas control system in which gases produced within the Sanitary Landfill are not completely contained within the boundaries of the Sanitary Landfill.

Gas Control System, Internal. A gas control system in which all gases produced by the Sanitary Landfill are completely contained within the boundaries of that Sanitary Landfill.

Geologic Hazard. A condition of the site geology inimical to standard construction practice.

Geologist. An approved Geologist duly qualified to make the investigations and prepare the geology reports required by this Code and capable of applying the geological sciences to engineering practice.

Grading. The act of excavating or filling or any combination thereof.

Ground Water. Any supply of water beneath the phreatic surface (water table).

Hazardous Substances. Highly flammables, toxic materials, and explosives.

Improvement. A structure, surface improvement, or subsurface improvement.

Incineration. A process of reducing the volume of combustible wastes by burning.

Inert. Earth, rock, gravel and other materials with inactive chemical properties.

Interface. The surface or surfaces common to the Sanitary Landfill and the original site or inert fill.

Leachate. The liquid that results when water comes into contact with refuse either by percolation or immersion.

Location, Class I. Sites located on non-water-bearing rocks, isolated from potable ground water by impermeable formations, or underlain by isolated bodies or normally unusable ground water, which are protected from surface runoff, and where safe limitations exist with respect to the potential radius of percolation.

Location, Class II. Sites underlain by normally usable, confined, or free ground water when an approved elevation of the landfill can be maintained above anticipated high ground water elevations, and which are protected from surface runoff and where surface waters can be restricted to the site or discharged to a suitable wasteway.

Location, Class III. Sites so located as to afford little or no protection to normally usable underground waters.

Materials, Class I. Any solid waste or liquid waste.

Materials, Class II. Solid waste that contains no hazardous substances but is comprised of such waste as ordinary household and commercial refuse and/or rubbish, garbage, other decomposable organic refuse, and demolition waste. Class II wastes may include, but are not limited to such materials as: (1) tin cans; (2) metals; (3) paper and paper products; (4) cloth and clothing; (5) wood and wood products; (6) lawn clippings, sod, and shrubbery; (7) hair, hide, and bones; (8) small dead animals; (9) roofing paper and tar paper; (10) unquenched ashes mixed with refuse; (11) market refuse; (12) garbage; and (13) all Materials, Class III.

Materials, Class III. Solid waste that contains no hazardous substances but also is comprised solely of non-water soluble, non-decomposable inert solids of the nature indicated by the following general materials; (1) earth, rock, gravel, and concrete; (2) asphalt paving fragments; (3) glass, ceramics, and inert plastics; (4) plaster and plaster board; (5) manufactured rubber products; (6) steel mill slag; (7) clay and clay products; and (8) asbestos shingles.

Noncombustible Waste. All solid waste not capable of incineration or burning, such as ashes, glass, metal, and earthenware.

Permittee. Any person, corporation, firm, governmental agency, or other entity to whom a permit has been issued under this Code.

Person. A natural person, his heirs, executors, administrators or assigns, and also includes a firm, partnership, or corporation, its or their successors or assigns, or the agent of any of the aforesaid.

Refuse. Any and all solid wastes.

Relief Vent. A vent, the primary function of which is to provide circulation of air between drainage and vent systems.

Reuse. To use over again or to make use of again.

Sanitary Landfill. A place where Sanitary Landfilling is practiced.

Sanitary Landfilling. A method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary.

Seepage Pit. A lined excavation in the ground which receives the discharge of a drainage system or part thereof, so designed as to retain the organic matter and solids discharging therein, but permitting the liquids to seep through the bottom and sides.

Settlement. Downward movement of a structure due to consolidation of underlying materials caused by dead and live loads and other forces and phenomena.

Shear Wall. A wall designed to resist lateral forces parallel to the wall, including, but not limited to braced frames subjected primarily to axial stresses.

Site. Any parcel of land or contiguous combination thereof shown on the last equalized assessment roll on which grading or Sanitary Landfilling construction is proposed or performed.

Site Classifications. See Location, Class I, II, and III.

Soils Engineer. An approved Engineer who is experienced in soil mechanics, investigating and reporting on the stability of existing or proposed slopes, controlling the installation and compaction of fills, determining soil bearing values, and providing design criteria and calculations for special earth structures.

Solid Waste. All solid or semi-solid materials, that the possessor considers of insufficient value to retain and for which he can find no market.

Stack. The vertical main of a system of soil, waste or vent piping extending through one or more stories.

Structural Improvements. That which is built or constructed, an edifice or building of any kind, or any piece of work artificially built up or composed of parts jointed together in some definite manner and attached to the land.

Subsidence. Downward movement of the ground surface on which no external loads have been imposed.

Subsurface Improvement. That portion of a structure, pipeline, conduit, vault, manhole, or improvement constructed below grade.

Sump. An approved airtight tank or pit which receives sewage or liquid waste, and which is located below the normal grade of the gravity system, and which must be emptied by mechanical means.

Surface Improvement. A street, driveway, sidewalk, curb, gutter, open ditch, channel, pipeline, or conduit or any portion thereof constructed to be of service at grade.

Ultimate Use. Utilization of a completed Sanitary Landfill for any purpose.

Vector. An animal or insect which transmits infectious diseases from one person or animal to another by biting the skin or by a mucous membrane or by depositing infected material on the skin, on food, or on another object.

Vent Stack. A vertical vent pipe installed primarily for the purpose of providing circulation of air or gas to or from any part of the drainage system or vent system.

Water Pollution. Any degradation of the quality of a usable surface or groundwater body.

CHAPTER 4. PERMITS, CERTIFICATES AND FEES

Sec. 401 Permits for Sanitary Landfill Construction and Operation

a. Permit Required. A permit shall be required for the construction, or operation of any Sanitary Landfill or portion thereof.

b. Preliminary Application for Sanitary Landfill Permit. A preliminary application, briefly describing the construction and operation of the Sanitary Landfill for which the permit is requested, and accompanied by a United States Geological Survey quadrangle map with the proposed Sanitary Landfill delineated thereon, shall be submitted to the Administrative Officer by the Applicant. After receiving the application, a preliminary site investigation will be made by the Administrative Officer. Preliminary approval of any concerned public or private agency or official, regarding the proposed construction, alteration, excavation, repair, or operation of a Sanitary Landfill upon such site shall be required by the Administrative Officer.

c. Notice of Disqualification for Sanitary Landfill Permit. The Administrative Officer shall notify the Applicant in writing, as to whether there is any apparent cause for summary disapproval. The involved agencies may recommend conditions for approval of the permit for which such preliminary application was filed. In the event such conditions are recommended, the Administrative Officer shall state such condition in such notice. In the event that the Applicant is advised that there is no apparent cause for summary disapproval, he then may file an application for a Sanitary Landfill permit.

d. Application for Sanitary Landfill Permit and Annual Renewal Permit. The Applicant for a permit to construct or operate a Sanitary Landfill shall submit to the Administrative Officer an application in the form and with the content prescribed by the Administrative Officer, and complete plans, drawings and operational procedures for the proposed facility including: (1) legal description of the site; (2) proof of ownership, lease, or permission of owner; (3) indication or statement of intent of compliance with all other affected ordinances and agencies and application for permits required by these agencies; (4) all maps, plans, drawings, specifications and reports required and previously submitted for the procurement of said permits; (5) the name, address, and telephone number of the Applicant and his principal officers; (6) the estimated dates for state and final completion of the project; (7) detailed drawings of all special constructions required herein; (8) an operating plan, including earth moving calculations showing the amount and type of available cover material using an approved soil classification systems terminology and the estimated daily and final cover material amounts needed; (9) a description of the types, probable quantities, and sources of materials and wastes to be received; (10) calculations arriving at the life expectancy of the site; (11) general plans showing approximate final grading, foliage, and drainage of the completed site; and (12) operating procedures to include hours and methods of operation, provisions for screening and for the prevention of blowing paper, and methods of collecting and reporting data on the quantities and types of refuse received, and other required information.

The Applicant also shall submit to the Administrative Officer an engineering feasibility report and contour map prepared by an Engineer. The contour map shall be at a scale of not over 200 feet to the inch with contour intervals of 5 feet for ground slopes between level and 50 percent; or 25 feet for ground slopes exceeding 50 percent. The report and map shall show: (1) the site and area surrounding the Sanitary Landfill; (2) the present contours, and proposed final contours; (3) contiguous waterways or surface drains; (4) existing capped or uncapped wells and available well logs, springs; (5) hydrological information; (6) intended points of ingress or egress; (7) access road; (8) location and types of fences and other provisions for controlling entry; (9) location of proposed final drainage structure, walls, cribbing, surface protection, and all other special constructions required by this ordinance; (10) fire protection provisions; and (11) decorative screening.

The Applicant also shall, if required by the Administrative Officer, submit a report prepared by a Geologist as to the allowable steepness of cut slopes at the boundaries of the site.

The Applicant also shall submit to the Administrative Officer a Geologist's report covering the general geology of the proposed site and the adjacent area one half mile beyond the site boundaries. This report will define the geologic structural conditions, surface and subsurface formations, the elevation of the present or anticipated groundwater level, and the direction of flow of groundwater.

Permits shall be renewed annually. A renewal application noting any operational changes for the following year's work shall be submitted to the Administrative Officer one month prior to expiration of the permit in effect.

e. Sanitary Landfill Faithful Performance Bond. The Applicant, as a condition of the issuance of a Sanitary Landfill permit, shall post a Faithful Performance bond with the Administrative Officer adequate to defray necessary expenses, in the amount that the Administrative Officer determines that is necessary to undertake corrective measures to protect the public health, safety, and welfare.

The bond may contain a provision giving the surety the option to cancel the bond upon first giving notice in writing not less than thirty days before the effective date of the cancellation to the Administrative Officer, providing that such cancellation shall not impair any right of the Adopting Agency to reimbursement for correction of conditions resulting from violations of such terms, conditions, laws, statues, ordinances or regulations, which violations occurred before the effective date of cancellation of the bond, whether the work of correction was performed before or after such effective date.

The Faithful Performance bond shall remain in effect until issuance of a Certificate of Completion.

The required bond may be in the form of bond from a corporation qualified to do business as a surety within the state, cash, or an approved letter of credit from a financial institution regulated by the Federal or State government.

f. Issuance or Denial of Sanitary Landfill Permit and Annual Renewal Permits. A permit shall be issued when the Administrative Officer finds that the work as proposed by the Applicant is not likely to adversely affect the stability of adjoining property or result in the deposition of debris on any public way or interfere with any existing drainage course or be in an area determined to be subject to geologic hazard, and the proposed uses shown on the plans for the site comply with all provisions of any applicable zoning ordinance, and further that all conditions and provisions contained herein for a Sanitary Landfill have been or will be met, fees paid, bonds posted, and proofs submitted.

Annual renewal permits will be issued when the Administrative Officer finds that the current work and any operational changes for the following year comply with the conditions of this Code.

If the Administrative Officer determines that a high water table elevation reasonably may be anticipated to rise, he may establish a new high water table elevation for the purpose of administration of this Code.

The Administrative Officer may condition the issuance of any permit upon any requirement deemed reasonably necessary to secure compliance with the provisions of this Code, including but not limited to, the recordation of documentation, in an approved form, guaranteeing the continuing responsibility for gas control and maintenance of a completed Sanitary Landfill.

An Applicant will be notified in writing if an application for a permit or renewal permit has been denied. The notification will state the basis for the denial.

g. Amendments to Permit. No major alterations of location, design, construction, or required appurtenances of a Sanitary Landfill for which a permit has been issued hereunder may be made until an amendment to such permit is issued by the Administrative Officer.

Application for such an amendment shall require;

(1) Proof of the concurrence of all other affected agencies; and,

(2) Submission of any plans, maps, drawings, specifications or on-site tests necessary to show that such alteration will continue to comply with all of the provisions of this Code.

The Administrative Officer shall issue such an amendment when he determines that such alteration will comply with all of the provisions of this Code.

h. Validity. The issuance or granting of a permit hereunder shall not be construed to be a permit for, or an approval of, any violation of any of the provisions of this Code or any other Code. No permit presuming to give authority to violate or cancel the provisions of this Code shall be valid.

The issuance of a permit based upon plans and specifications shall not prevent the Administrative Officer from thereafter requiring the correction of errors in said plans and specifications or from preventing construction, modification, alteration, repair or operations being carried on thereunder when in violation of this Code.

i. Expiration. Every permit issued by the Administrative Officer under the provisions of this Code shall expire by limitation and become null and void one year after the date of issuance, or if the construction, alteration, repair, or operation authorized by such permit is not commenced within 120 days or authorized extension thereof from the date of such permit, or if the construction, alteration, repair or operation authorized by such permit is suspended or abandoned at any time after the work is commenced for a period of 120 days. Before abandoned or suspended work can be recommenced, a new permit shall be first obtained so to do, and the fee therefor shall be 1/2 the amount required for a new permit for such work, provided no changes have been or will be made in the original plans and specifications for such work; and provided, further, that such suspension or abandonment has not lasted beyond the permit renewal date.

j. Fees. A fee for each preliminary application, application, permit, and permit renewal hereunder shall be paid to the Administrative Officer, as follows:

(To be established by local agency.)

Where work for which a permit is required by this Code is started or proceeded with prior to obtaining said permit, the fees above specified shall be doubled, but the payment of such double fees shall not relieve any persons from fully complying with the requirement of this Code in the execution of the work nor from any other penalties prescribed herein.

k. Costs. All expenses or costs of testing, monitoring, sampling, boring, gas control systems, subsidence monitoring devices, subsidence monitoring surveying, and all other actions required to be taken by the Permittee or Applicant hereunder, shall be borne by such Applicant or Permittee.

CHAPTER 5. SUPERVISION OF SANITARY LANDFILL OPERATIONS

Sec. 501 Supervision by Permittee

The Permittee shall provide responsible supervisory control during grading and landfilling operations to insure compliance with approved plans and with all applicable codes. When required by the Administrative Officer, the Permittee shall secure: (1) engineering and/or (2) geological and/or (3) foundation engineering services to implement supervisory control. The Engineers or Geologists shall be qualified as specified in this Code.

The Permittee shall submit periodic progress reports as required by the Administrative Officer and shall certify in writing to the satisfactory completion of the various stages of the work. The Administrative Officer may require sufficient inspections by the Geologist to assure that all geological conditions have been adequately considered and necessary corrective measures incorporated in the work. All necessary reports, soil compaction data, and soils engineering or engineering geological recommendations made during the filling operations shall be submitted to the Administrative Officer.

Sec. 502 Inspection of Sanitary Landfills

The Administrative Officer will inspect every Sanitary Landfill located within his jurisdiction. In case the Administrative Officer discovers a violation of any item pertinent to the provisions of this Code, he shall issue a Notice of Violation as provided in Section 605 hereof. After issuance of any such Notice of Violation, the Administrative Officer shall make such further inspections as he may deem necessary to determine whether all violations which are the cause for such Notice of Violation have been corrected. After the lapse of 10 days or other such time as the Administrative Officer has specified on the Notice of Violation for such violations to be remedied, such violations shall be deemed a willful failure to comply with the provisions of this Code or condition of such permit, and cause for suspension or revocation of permit, or action upon the bond.

One copy of the inspection report, on which violations of any item of sanitation pertinent to the provisions of this Code shall be inscribed, shall be left at the landfill site by the Administrative Officer. Another copy of the aforementioned inspection report shall be filed by the Administrative Officer with the records of the Adopting Agency and be available to the public during regular business hours.

CHAPTER 6. ENFORCEMENT

Sec. 601 Right of Entry

Upon presentation of proper credentials the Administrative Officer or his duly authorized representative or deputy may enter at reasonable times any part of any Sanitary Landfill or improvement to perform any duty imposed upon him by this Code. No person, firm or corporation shall deny or prevent, obstruct, or attempt to deny, prevent, or obstruct such entry.

Sec. 602 Liability

The Administrative Officer or any of his duly authorized representatives or deputies charged with the enforcement of this Code, acting in good faith and without malice, in the discharge of his duties, shall not thereby render himself personally liable and he hereby is relieved from all personal liability for any damage that may accrue to persons or property as a result of any act required or by reason of any act or omission in the discharge of his duties. Any suit brought against the Administrative Officer or his duly authorized representative or deputy, because of such act or omission performed by him in the enforcement of any provision of this Code, shall be defended by the legal counsel for the Adopting Agency.

Sec. 603 Cooperation of Other Officials

The Administrative Officer may request, and shall receive, so far as may be necessary for the discharge of his duties, the assistance and cooperation of other officials of the Adopting Agency.

Sec. 604 Violation Deemed Nuisance

The construction, alteration, repair, operation or use of any Sanitary Landfill or improvement in violation of any of the provisions of this Code or the conditions or any permit or certificate hereunder, hereby are declared to be public nuisances and shall be abated by alteration, repair, rehabilitation, demolition, or removal, in accordance with the procedures specified in this Chapter.

Sec. 605 Notice of Violation

If at any stage of the work, the Administrative Officer determines by inspection that;

(1) Work is being done contrary to this Code, the permits/certificates issued hereunder or approved plans; or,

(2) Further work as authorized is likely to endanger any person, property (public or private), or water course or result in the deposition of debris on any public way; then,

he may order the work stopped by a written Notice of Violation served on any person(s) engaged in doing or causing such work to be done. The person(s) shall forthwith stop such work immediately after the receipt of this notice. The conditions shall be corrected by prescribed and stated methods of abatement within 10 days or other such time limit prescribed on the Notice of Violation. The Administrative Officer shall authorize the work to proceed if he finds adequate corrective measures have been taken.

Sec. 606 Abatement

After Notice of Violation has been served upon the owner or person in charge or control of a Sanitary Landfill or improvement and the violation has not been corrected within the time limit prescribed on the Notice of Violation, and no appeal has been taken, the Administrative Officer may abate the public nuisance by the methods described in the Notice of Violation.

Sec. 607 Abatement Costs

The entire costs to the Adopting Agency of abatement pursuant to the provisions of the preceding section may become a special assessment against the property upon which the abatement occurred as hereinbelow described. The Administrative Officer shall notify, in writing, all parties concerned of the amount of such assessment resulting from such work. If the total assessment determined as provided for in this subsection is not paid in full within ten (10) days after receipt of such notice from the Administrative Officer or the Board of Appeals, as the case may be, the Administrative Officer shall record in the Office of the County Recorder a statement of the total balance still due and the legal description of the property. From the date of such recording, such balance due shall be a special assessment against the property.

The assessment shall be collected at the time and in the same manner as ordinary taxes of the Adopting Agency are collected, and shall be subject to the same penalties and the same procedure and sale in case of delinquency as provided for ordinary taxes of the Adopting Agency. All the laws applicable to the levy, collection and enforcement of the taxes of the Adopting Agency shall be applicable to such special assessment.

Sec. 608 Appeals of Notices of Violation and Abatement Costs

Within ten (10) days after receipt of a Notice of Violation, the Permittee may file an appeal, in writing, with the Administrative Officer and Board of Appeals. The Board of Appeals, upon the giving of ten (10) days written notice to the appellant and the Administrative Officer, shall hold a public hearing to determine the question of whether the alleged violation has occurred, and whether the proposed methods of abatement are reasonable.

All interested parties who desire to be heard may appear before the Board of Appeals to show cause why the Sanitary Landfill or improvement construction, alteration, repair, maintenance or operation is not in violation of this Code, the permit therefor, or any rule or regulation of the Administrative Officer or why the proposed method of abatement is not reasonable.

Not less than ten (10) days prior to the hearing the Board of Appeals shall serve a notice of hearing upon every party concerned, and post same in a conspicuous place on the premises of the facility involved.

The notice of hearing shall state:

(1) The street address and a legal description sufficient for the identification of the premises upon which the Sanitary Landfill or improvement is located.

(2) The conditions because of which the Administrative Officer believed that the Sanitary Landfill or improvement was a violation of a provision of this Code, a condition of the permit for such Sanitary Landfill or improvement, or the rules and regulations of the Administrative Officer adopted pursuant hereto.

(3) The proposed method of abatement of the alleged violation.

(4) The date, hour and place of the hearing.

The Board of Appeals shall hold a public hearing and consider all competent pertinent evidence offered by any person pertaining to the questions to be decided by the Board of Appeals.

The Board of Appeals shall make written findings of fact as to whether or not the Sanitary Landfill or improvement is in violation of a provision of this Code, the permit or certificate issued hereunder for such Sanitary Landfill or improvement, or the rules and regulations of the Administrative Officer adopted pursuant hereto.

If the Board of Appeals finds that the Sanitary Landfill or improvement is in violation of this Code or such permit, certificate, or rules and regulations, it shall make an order based upon its findings that such a violation has occurred and also shall determine and order the reasonable abatement thereof.

The order shall state the time within which the work required must be commenced, which shall not be less than ten (10) nor later than thirty (30) days after service of the order. The order shall state a reasonable time within which the work shall be completed. The Board of Appeals for good cause may extend the time for completion in writing.

The order shall be served upon the same parties and in the same manner as is required for the notice of hearing. It also shall be conspicuously posted on or about the Sanitary Landfill or improvement.

Within five (5) days of receipt of a notice of assessment for abatement costs, any party concerned may file with the Board of Appeals a written request for a hearing on the correctness or reasonableness, or both, of such assessment. Any party concerned who did not receive such a notice and who has not had a hearing on the necessity of the demolition or repairs, in such request for hearing also may ask that such necessity be reviewed. The Board of Appeals shall thereupon set the matter for hearing, give such party concerned ten (10) days' written notice thereof, hold such hearing and determine the reasonableness or correctness of the assessment. The Board of Appeals, in writing, shall notify such party concerned of its decisions.

Sec. 609 Revocation or Suspension of Permit

The Administrative Officer, after notice and hearing as provided for appeals in this Chapter, may revoke or suspend any permit or approval issued hereunder upon his finding that:

(1) Such permit was issued in error or was issued on the basis of false information furnished to the Administrative Officer by the Permittee, and no substantial reliance in good faith to the Permittee has occurred; or,

(2) Such permit was secured by the fraud of the Permittee; or,

(3) The Permittee or party to whom such permit was issued has willfully failed to comply with any provisions of this Code or condition of such permit.

Sec. 610 Service

Whenever in this Chapter a notice is required to be served, such notice shall be served by registered or certified mail addressed to the Permittee or party to whom a certificate was issued hereunder at the address shown on the application for such permit or certificate or subsequent written notification of change of address of such Permittee or party delivered to the Administrative Officer.

Sec. 611 Emergency Dangerous Conditions

Whenever any Sanitary Landfill or improvement or portion thereof constitutes an immediate hazard to life or property, and in the opinion of the Administrative Officer the conditions are such that abatement of such a condition must be undertaken within less than the period designated for perfection of Notice of Violation and appeal, he may order the Permittee to abate or he may make such an abatement as is necessary to protect life or property, or both, after giving such notice to the parties concerned, as the circumstances will permit, or without any notice whatever when, in his opinion, immediate action is necessary.

CHAPTER 7. CERTIFICATIONS

Sec. 701 Certificate of Completion

a. Certificate Required. No use of a completed Sanitary Landfill may be made until a Certificate of Completion has been issued by the Administrative Officer.

b. Application. Whenever any Sanitary Landfill has been completed and is proposed for use, the owner of such Sanitary Landfill shall file an application for a Certificate of Completion with the Administrative Officer.

c. Issuance. A Certificate of Completion shall be issued to the owner of a Sanitary Landfill for which a permit has been issued hereunder, when the Administrative Officer determines that all conditions of such permit have been fulfilled.

d. Release of Faithful Performance Bonds. Upon the issuance of a Certificate of Completion hereunder the Faithful Performance bond required hereunder shall be released.

e. Costs. All expenses and costs for testing, monitoring, sampling, boring, gas control systems, subsidence monitoring devices, subsidence monitoring surveying, and all other tests, surveys, or requirements determined to be necessary by the Administrative Officer for issuance of the Certificate of Completion hereunder shall be paid by the Applicant for such Certificate of Completion, prior to issuance thereof.

f. Partial Completion. Application may be submitted for a Certificate of Completion for a portion of a completed Sanitary Landfill.

Sec. 702 Revocation or Suspension of Certificate of Completion

The Administrative Officer, after notice and hearing as provided for appeals in this Chapter, may revoke or suspend any certificate issued hereunder upon his finding that:

(1) Such certificate was issued in error or was issued on the basis of false information furnished to the Administrative Officer by the Permittee, and no substantial reliance in good faith to the detriment of the Permittee has occurred; or,

(2) Such certificate was secured by the fraud of the Permittee; or,

(3) The Permittee or party to whom such certificate was issued has willfully failed to comply with any provisions of this Code or condition of such permit.

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UNIFORM STANDARDS FOR LOCATION, DESIGN, CONSTRUCTION, AND MAINTENANCE OF SANITARY LANDFILLS SUBJECT TO SANITARY LANDFILL CODE

The short title of this document shall be "Uniform Standards."

Standard 1. Permitted Location

a. General. A Sanitary Landfill shall be permitted only at a location meeting the following requirements:

(1) A Sanitary Landfill at such location will not be materially detrimental to the public welfare or to other property located in the vicinity;

(2) A Sanitary Landfill at such location will not adversely affect the provisions of any community general plan regarding facilities for solid waste management; and,

(3) A Sanitary Landfill at such location conforms to all applicable state and local health, safety and zoning laws.

b. Conformity With General Plan. The development of a completed Sanitary Landfill, or planning or dedication of land for streets, highways, alleys or other public use, shall conform with all applicable community general plans of streets and highways, and shall make provision for the continuation of principal existing streets.

Sanitary Landfills with fills no deeper than 50 feet, shall be designed and constructed in such a way that at finish grade they shall have inert fill bases for roadways provided by general plan and, if required by appropriate agency, building pads for future buildings.

c. Access. The Administrative Officer may designate the routes of ingress and egress to or from a Sanitary Landfill site, when it is determined to be necessary for the interest of the public health, safety, and welfare. Such designation of routes shall take into consideration the most practical means of access.

Access roads and staging areas shall be provided so that vehicles waiting to enter the Sanitary Landfill area shall not impede the flow of traffic on public streets.

Dust-free access roads, negotiable at all times by loaded refuse collection vehicles, shall be provided and maintained to the face of the Sanitary Landfill. They shall be sprayed, filled, repaired, regraded, and relocated as necessary.

Clearly marked directional signs shall be prominently located at all times along the Sanitary Landfill road leading to the unloading area.

Standard 2. Operation Regulations

a. General. The disposal of all solid waste shall be by the method commonly known as the "Sanitary Landfilling" method, by means of either a "fill and cover" or "cut and cover" type of operation, in which the dumped material is compacted and completely enclosed daily with an earth cover in compliance with these Uniform Standards.

A Sanitary Landfill shall be operated only in accordance with the plans, drawings, and specifications which are a condition of the Sanitary Landfill permit.

Any change in such approved plans, drawings and specifications must be requested in writing by the Permittee and approved. If any such changes are approved, notice thereof will be given in writing to such Permittee by the Administrative Officer.

The Permittee shall accept only materials permitted by this Code for the Sanitary Landfill classification of the site and which are submitted for disposal during his posted hours of operation.

The Permittee shall not permit any violation of any applicable dumping regulations, and the Permittee shall maintain such patrols or policing services as are necessary to prevent violations.

No Sanitary Landfill shall willfully terminate operations for any period longer than 48 hours without advance notice of 24 hours to the Administrative Officer, and approval.

All operators of Sanitary Landfills shall keep and maintain records of their operations and shall, if requested by the Administrative Officer, submit periodic reports on such operations. The records shall contain: (1) the number of loads of refuse daily; (2) total weight of refuse received when scales are available; and (3) abnormal occurrences in the operation of the site.

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b. Burning. Burning shall not be allowed in or upon a Sanitary Landfill. Also, the Permittee shall prevent the ignition of the Sanitary Landfill or any other flammable material, surface or subsurface on the site.

c. Salvage. Salvage and reclamation operations may be established at designated locations away from the working face, if the Administrative Officer determines that such operations are compatible with the purposes and objectives of this Code. Design, operation, and maintenance plans for such operations must first be approved by the Administrative Officer.

Standard 3. Permitted Materials

a. Waste Materials. Approved materials, Class I may be accepted only at Location, Class I sites. Materials, Class II may be accepted only at Location, Class I and Location, Class II sites. Materials, Class III may be accepted at Location, Class I, II, or III sites.

Approved liquids may be accepted at Location, Class II sites only if utilized as a moisture ingredient to aid in solid waste compaction.

Approved liquid cannery wastes, large dead animals, treated semi-solid wastes from sewerage and water processing systems, poultry hatchery wastes, meat packing and similar wastes may be acceptable if approved handling and spreading techniques are continuously employed.

Liquids from septic tanks, seepage pits, or sumps shall not be accepted at or be allowed to drain onto or into a Sanitary Landfill except at Location, Class I sites and then only if approved disposal methods are employed.

Hazardous substances shall not be accepted except at Location, Class I sites and then only if approved disposal methods are employed.

Radioactive materials shall not be accepted at Sanitary Landfills.

b. Cover Materials. Cover materials shall be inert, and shall be free of putrescible materials, large objects, and combustible materials.

The following types of soil as defined by an approved soil classification system and materials shall not be used as final cover materials:

(1) Clay;

(2) Organic soil; and,

(3) Incinerator residue.

EXCEPTION: The Administrative Officer may authorize an exception to the above requirements if he determines that such an exception would not create a hazard or nuisance.

Standard 4. Water Pollution

a. Location Requirements. A Sanitary Landfill located upon a soil of relatively low permeability shall be separated vertically from the high water surface of underlying normally usable ground water by a minimum distance which the Administrative Officer approves or determines is necessary to prevent pollution of such underlying normally usable ground water.

A Sanitary Landfill shall not be located in an area where the adjacent or underlying soils are highly permeable and underlain by normally usable ground water.

EXCEPTION: The Administrative Officer may authorize an exception to such requirement, if the governmental agency responsible for ground water protection approves a method of protection.

A Sanitary Landfill site subject to intrusion of fresh waters, sea water, or waters of high sulfate content, shall be limited to deposit of Materials, Class III.

b. Engineering Requirements. Construction plans shall show methods of minimizing or preventing:

(1) Water draining upon or otherwise applied to the surface and percolating vertically through the soil cover;

(2) Water from an adjacent source moving horizontally through the side of the fill;

(3) Water entering from the bottom of the fill due to a rise in the ground water table or capillary action;

(4) Water being present in the fill site prior or during placement of refuse material; and,

(5) Leachates.

Periodic sampling and laboratory testing of water from a representative well or wells located in the area adjacent to the Sanitary Landfill site may be required by the Administrative Officer at any time.

c. Installation Requirements. Off site surface waters shall be diverted or conveyed from the site so as to prevent percolation through any of the dumped material or erosion of the cut sections of the Sanitary Landfill.

A Sanitary Landfill bounded by highly permeable soils may be required to have well points located at selected points along or beyond the Sanitary Landfill boundaries. Well points outside the boundary of the Sanitary Landfill will not be required if established wells in the area are approved, or if suitable locations cannot be obtained for establishing the well points.

Standard 5. Gas Control

a. Function Requirements. Migration of gases into property adjacent to a Sanitary Landfill site shall be prevented. All plans and data for the construction of Sanitary Landfills Location, Class II and Location, Class I shall specify, and show by drawings, methods proposed to prevent the off site movement of gases.

The Applicant shall submit data, prepared by an Engineer, showing the predictability of gas movement, including but not limited to density, porosity, particle size distribution, and moisture content of soils on the site, and adjacent to the site.

EXCEPTION: The Administrative Officer may authorize an exception to such requirements if he determines that monitoring or other data available or presented is sufficient to show the predictability of such gas movement; or where the owner of the site files a covenant with the land limiting the use of that portion of the property within (1000) one thousand feet of the interface to non-occupant type construction.

b. Gas Monitoring. An approved gas monitoring system shall be installed along the boundary of the landfill to insure that gas is not allowed to migrate from the site.

Gas monitoring shall be done during construction of the Sanitary Landfill at periodic intervals not to exceed six months.

All completed Location, Class I and Location, Class II Sanitary Landfills shall be monitored for gas production and migration not less than once annually, except those showing no gas production for five consecutive years. All data collected shall be permanently recorded by the operator. Copies shall be submitted to the Administrative Officer after each test. If gas migration is considered excessive, the Administrative Officer shall require that the operator or owner in the case of a completed landfill, immediately provide such gas control measures as are necessary to prevent further gas migration from the site.

Prior to the issuance of a Certificate of Completion for a completed Sanitary Landfill, the Administrative Officer shall determine that the approved monitoring system is in working order. The landfill operator or subsequent owner shall continue routine monitoring of the system after completion of the landfill and this requirement shall be binding on and recorded so as to run with the land.

c. Gas Control Systems. Materials utilized for gas barriers shall: (1) be inert and impervious to moisture and gas; (2) maintain continuous qualities under conditions encountered in the fill including alternate wet and dry cycles; and (3) be located to be effective as a cutoff.

Gas control systems, barriers, seals and required installations shall not be covered prior to inspection and approval of the installation.

d. Installation Requirements. Gas control seal barriers shall be designed to be minimally affected by subsidence.

All sharp sticks, stones, and trash shall be removed or covered with soil prior to the installation of a flexible gas barrier. Areas containing grass shall be sterilized. The area to be covered shall be compacted and smoothed to reduce stresses in the membrane. Mechanical equipment shall not be driven directly onto the liners unless it is proven to the Administrative Officer, on the job site, that damage will not result.

Torch type refuse gas burners shall be fitted with a flashback prevention device. Combustion air openings within the gas pipe shall not be located below the burner but may be located above the cover plate.

Standard 6. Subsidence Monitoring

Before a Certificate of Completion is issued, the site shall be provided with benchmarks for determination of subsidence of the landfill area.

A minimum of two permanent benchmarks shall be established at approved locations outside the perimeter of the Sanitary Landfill, unless benchmarks established by a Federal, State, County, or City agency are available.

For measurement of the amount of vertical subsidence, approved benchmarks shall be established on the Sanitary Landfill site approximately 200 feet apart in a rectangular pattern.

The elevations of all the benchmarks shall be determined upon completion of the fill and a record of these elevations shall be furnished the Administrative Officer. The owner of a completed Sanitary Landfill shall protect and maintain the benchmarks and shall cause the elevations of the benchmarks to be determined at periodic intervals not to exceed two years. A record of these periodic surveys shall be furnished to the Administrative Officer.

Standard 7. Excavation, Grading, Landfilling, and Drainage of a Sanitary Landfill

a. Supervision. The Permittee, or his authorized representative, shall be present during all operations and shall control and supervise activities.

b. Refuse Placement. As rapidly as solid waste is admitted to the site it shall be spread and compacted in layers not to exceed two feet in depth after track or roller compaction.

The working face shall be kept as confined as possible consistent with providing sufficient dumping area for the incoming vehicle. In no event shall the open face exceed 10 feet in length for each 100 tons per day except that small sites handling less than 500 tons per day will be allowed fifty feet of open face.

c. Daily Covering. Both the exposed refuse surface and the face of all Sanitary Landfills shall be covered an approved depth with a layer of earth at the end of each working day so that no refuse is exposed thereby making a closed cell of each day's deposit.

d. Final Covering. The final cover for any Sanitary Landfill shall be a minimum depth of three feet. In no case shall any permanent excavation reduce the cover to less than three feet. Operations on an interim surface or any portion of the Sanitary Landfill shall not be suspended more than 120 days unless a final cover has been applied.

e. Slope Stability Requirements. No final fill slope shall exceed a vertical height of 50 feet unless horizontal benches with a minimum width of 15 feet are installed at each 50 feet of vertical height.

No fill shall be made which creates a finished surface steeper in average slope that two horizontal to one vertical. The fill slopes abutting and above public property shall be so placed that no portion of the fill lies above a plane through [illegible] public property line extending upward at an average slope of two horizontal to one vertical.

Tops of cut slopes in natural ground shall not be made nearer to a property line than three feet, or 1/5 the height of the cut, whichever is greater, but need not exceed a horizontal distance of ten feet.

Toes of fill slopes shall not be made nearer to a Sanitary Landfill boundary line than 1/3 the height of the fill, but need not exceed a horizontal distance of 20 feet.

Where the excavation exposes strata above the top of the cut which will permit the entry of water along bedding planes, this area shall be sealed with a relatively impervious compacted soil blanket having a minimum thickness of two feet, designed by a Soils Engineer, and subject to approval.

If the material of the slope is of such composition and character as to be unstable under the anticipated maximum moisture content, the slope angle shall be reduced to a stable value. This requirement shall be confirmed by the Soils Engineer's written certification.

f. Drainage. Permanent drainage facilities on operating and completed sites shall be designed for a flooding hazard frequency of once in fifty (50) years.

The daily and final surface of a Sanitary Landfill shall have a graded slope of no less than 2 percent to prevent ponding of water.

g. Miscellaneous. A Sanitary Landfill in an abandoned strip coal mine shall comply with the following: (1) the coal vein shall be covered an approved depth with an insulating blanket of non-combustible material; and (2) no rider veins shall be exposed.

Swamp areas shall be diked, drained and inspected prior to commencement of operations.

Sanitary Landfilling methods employing the trench system may be approved if successive parallel trenches are at least three feet apart.

Standard 8. Requirements for Health and Safety

a. Fire Prevention. A water supply, capable of flowing not less than 250 gallons per minute at a minimum of 20 psi residual pressure for a period of not less than 1-1/2 hours, shall be provided on the site.

Water mains, not less than 4 inches in diameter, shall be installed with fire hydrants having a 2-1/2 inch outlet attached thereto with a 4 inch riser. Water mains and hydrant locations shall meet the approval of the Fire Department of the public agency within whose jurisdiction the Sanitary Landfill is located.

Hydrants, pipes, and standpipes shall be protected from mechanical injury, and adequate shutoff valves shall be provided to control the system.

A firebreak or clearance of all dry weeds and grass shall be provided around the dumping areas, and secondary firebreaks as required by the Fire Department of the public agency within whose jurisdiction the Sanitary Landfill is located, shall be provided and maintained, in order to prevent the spread of fire beyond the facility. Such secondary firebreaks shall be the width specified by the Fire Department.

Weeds, grass, and combustible vegetation shall be removed for a distance of 15 feet on both sides of all access roads used by rubbish trucks or the public.

"NO SMOKING" signs shall be posted on the Sanitary Landfill and at all entrances to such Sanitary Landfill, and smoking regulations as required by the Fire Department of the public agency within whose jurisdiction the Sanitary Landfill is located shall be strictly complied with.

Any fire which occurs on the premises shall be reported immediately to the Fire Department of the public agency within whose jurisdiction the Sanitary Landfill is located, and it shall be the responsibility of the Permittee to immediately extinguish any such fire.

Refueling operations and installations shall be in accordance with any applicable Fire Code or regulation.

b. Sanitary Facilities. Separate sanitary facilities shall be provided on the Sanitary Landfill site for employed personnel as required by the Health Department.

c. Vectors. Monitoring of pests and vectors shall be made by the Permittee at least once a week for rodent burrows, droppings, or other evidence of rodents or insect breeding. Any infestation shall be controlled as necessary by approved methods.

d. First Aid. A first aid kit, equipped with sterile bandages, snake bite kits, antiseptic solutions, tourniquets, splints, and other necessary supplies shall be at the site.

e. Utilities. Telephone or radio communication facilities shall be provided which are readily accessible to the employees in the event of an emergency.

Lights shall be provided for any approved night operations.

f. Fencing. A Sanitary Landfill site shall be fenced and provided with lockable gates, to prevent access by unauthorized persons during non-working hours.

EXCEPTION: Areas to which access is limited by topography or other natural barriers to one route, are not required to be fully fenced, if a lockable gate which controls access is provided.

Standard 9. Landscaping and Erosion Control Planting Where Soil Conditions Permit

All finished fill or cut slopes in Sanitary Landfills shall be planted and irrigated with a sprinkler system to provide a growth of approved grass or ground cover plants to protect the slopes against erosion.

Sprinkler systems shall be designed to provide a uniform water coverage at a rate of precipitation of not less than 1/10 inch per hour nor more than 3/10 inch per hour on the planted slope. In no event shall the sprinkling be permitted to create a saturated condition and cause an erosion problem or allow the discharge of excess water into any public or private street.

A check valve and balance cock shall be installed in the system where drainage from sprinkler heads would create an erosion problem.

Standard 10. Maintenance

a. Surface and Slope. Daily, interim and final cover shall be maintained by the Permittee during construction and after completion of the Sanitary Landfill. The slope of the daily and final cover shall be maintained to prevent ponding prior to successive lift operations. Depressions which form and trap surface water shall be filled within

72 hours after weather conditions permit. Surplus cover material shall be available at the completed fill for regrading and filling surface cracks which may develop in the finished fill. Slopes which have been seeded as a requirement of this Code shall be reseeded by the Permittee when required to establish uniform continuous cover, erosion resistant drainage, and green foliage.

b. Equipment. The Sanitary Landfill operator shall maintain his working equipment in good mechanical condition, and all internal combustion motors must have adequate mufflers to minimize noise.

Required equipment, or a suitable substitute therefore, shall be ready for operation during all permitted dumping hours. Operational maintenance shall be scheduled to comply with this requirement. Auxiliary equipment shall be of sufficient capacity to insure continuous and proper operation of the Sanitary Landfill during critical and peak-load periods.

SUGGESTED ADDENDA TO BUILDING CODES RE: DESIGN AND CONSTRUCTION OF STRUCTURAL IMPROVEMENTS ON, AND IMMEDIATELY ADJACENT TO SANITARY LANDFILLS

1. Regulation of Building on Sanitary Landfill or Existing Dumps

a. General. No permanent building or structure shall be constructed on any Sanitary Landfill unless provisions are made to support it on pilings or in such other manner that it does not depend on the Sanitary Landfill for any portion of its support. In addition, where buildings or structures are constructed on Sanitary Landfills and such alternate support is provided, adequate provision shall be made to prevent the accumulation of decomposition gases within or under enclosed portions of such buildings or structures and to prevent damage to structure, floors, underground piping and utilities due to uneven settlement of the fill.

Where the depths of Sanitary Landfills are too great to allow the installation of piling or the means of independent support, the use of the complete Sanitary Landfill shall be limited to such open space uses as parks, golf courses, parking areas, storage yards, truck terminals, nurseries or similar uses not requiring closed buildings.

The installation of mobile buildings will be permitted on Sanitary Landfills provided adequate ventilation systems are provided, and utility systems can be installed in compliance with local engineering regulations relating to the construction of subsurface improvements on a Sanitary Landfill.

Prohibited uses and construction on a Sanitary Landfill also are prohibited on an existing dump.

b. Foundation Support. Piling which penetrates the active portion of the Sanitary Landfill shall be designed for the applicable horizontal loads due to: (1) seismic; (2) wind loads; and (3) equivalent hydrostatic pressure. Stresses which are induced by acceptable pile displacements shall be considered in the design of struts, grade beams, and slabs to which each may be connected.

Piling penetrating the active portion of a Sanitary Landfill shall be designed for the down-drag effects of frictional resistance to subsidence and settlement from the surface to the bottom of the pile.

Floor loads shall be transmitted directly to piling which penetrates the active portion of the Sanitary Landfill. Floor loading calculated for this purpose shall include dead load plus one-half live load. Warehouse type loading shall be considered as dead load for this purpose.

Non-habitable one-story light-frame accessory structures not exceeding 400 square feet in area nor 12 feet in height may be constructed without special provision for foundation stability.

c. Gas Control. Gases shall not be allowed to concentrate in confined areas in improvements. Approved methods of preventing this condition include barriers, vents, and mechanical ventilation systems. Structures built upon a Sanitary Landfill shall be equipped with gas control systems.

Utilities entering a structure below grade through holes, openings or casings and which do not fill the space, shall be fitted with approved gas barriers.

Interior plumbing systems shall be vented to prevent the intrusion of Sanitary Landfill gases into buildings constructed on a Sanitary Landfill. The vent system may be designed in approved combination with the internal system, or shall be vented by an independent vent stack, exterior to the building.

All electrical switching and instrumentation installed in ground vaults or in unventilated spaces within a building constructed on a Sanitary Landfill shall be vented to prevent accumulation of gases or shall be explosion-proof.

2. Regulation of Building on Solid or Compacted Soil Immediately Adjacent to a Sanitary Landfill but Within the Site Boundary

a. General. Buildings and other structures built on original or compacted earth within the boundaries of a landfill site shall conform with all applicable requirements of the Building Regulations of the Adopting Agency. Such buildings or struct~~ures~~ shall also be provided with such gas monitoring or control systems as are required herein.

b. Gas Control. If a building or structure is to be located within the landfill site on solid ground, it shall be equipped with a gas control system unless there is a sufficient barrier of impermeable soil between the proposed structure and the Sanitary Landfill to prevent gas from migrating to the building.

SUGGESTED ADDENDA TO LOCAL ENGINEERING REGULATIONS RE: DESIGN AND CONSTRUCTION OF SURFACE AND SUBSURFACE IMPROVEMENTS

Sec. 1 Surface Improvements

a. Gas Control. Gases shall not be allowed to concentrate in confined areas of surface improvements. Approved methods for preventing this condition include barriers, vents, and mechanical ventilation systems.

b. Subsidence and Differential Settlement Control. Surface improvements having drainage requirements shall be designed to minimize the effects of differential settlement by approved methods.

Funding for maintenance of all improvements not located on inert or structural foundations shall be provided.

Drainage channels which are provided with overlapping sections shall have supports at the points of overlap deep enough to function as subsurface cutoff walls.

Surface improvements intended to transport surface waters shall be replaced if cracked or otherwise damaged in such a manner as to permit surface water to enter the Sanitary Landfill.

Streets, curbs, gutters and sidewalks traversing the waste filled portion of a Sanitary Landfill shall be designed of flexible paving materials.

Fences and walls constructed on a Sanitary Landfill shall be of a design that will tolerate substantial settlement without failing. Rigid masonry or concrete construction will not be permitted.

Surface and subsurface improvements in juxtaposition with pile founded structures shall be provided with approved methods of accommodating differential settlement.

Sec. 2 Subsurface Improvements

a. Gas Control. Gases shall not be allowed to concentrate in confined areas in subsurface improvements. Approved methods for preventing this condition include barriers, vents, and mechanical ventilation systems.

The intrusion of gases into substructures such as manholes, vaults, and underfloor areas shall be prevented by the use of approved barriers or ventilation. Substructures built upon a Sanitary Landfill shall be equipped with gas control systems.

b. Subsidence and Differential Settlement Control. All subsurface improvements shall be designed to minimize the effects of differential settlement by approved methods.

Underground natural gas mains in a Sanitary Landfill shall be provided with valves near the interface and not on the Sanitary Landfill. Individual gas services shall be provided with shutoff valves at the mains.

Sec. 3 Maintenance

Required slopes, separation distances and decorative landscaping on a Sanitary Landfill shall be maintained by the Permittee.

All permanent and temporary structures located on a Sanitary Landfill shall be maintained in compliance with the provisions of all legal requirements for sanitation, safety and appearance, and all other applicable laws. Structures on an operating Sanitary Landfill shall be maintained in good repair.

A permanent set of building plans and design calculations, if any, for any structure founded fully or partially on a Sanitary Landfill shall be retained by the owner for the economic life of the structure.

Separation of any portion of a structure, dock, stoop, or other facility resting at grade on a Sanitary Landfill in excess of 1-1/2 inches vertically or 1 inch horizontally shall be repaired or replaced.

Surface improvements shall be maintained in good condition. Damaged ditches, culverts, or gutters on a Sanitary Landfill which have been subjected to changes in slope resulting in excessive silting, scouring, or permitting water to enter the Sanitary Landfill, shall be repaired or replaced. Gutters with cracks which permit water to enter the subgrade shall be repaired or replaced.

Curbs or gutters with cracks in excess of 1/2 inch vertical difference and 1 inch horizontal difference shall be repaired or replaced.

Streets with cracks in excess of 1/2 inch vertical difference or 1/2 inch horizontal displacement shall be repaired or replaced.

Sidewalks which have settled differentially to a cross slope of 1/2 inch per foot or which have cracks in excess of 1/4 inch vertical difference or 1/2 inch horizontal displacement shall be repaired or replaced.

Underground gravity or pressure lines which rupture and admit liquid or gas into the Sanitary Landfill shall be taken out of service and excavated to locate the rupture. Softened or washed out areas below the bedding shall be excavated and backfilled to the bedding plane prior to further inspection and backfilling. All softened and disturbed material shall be excavated prior to final backfill, rough grading and finish grading.

Gas control devices and systems shall be maintained. Cracks, fissures, washouts, or other failures, or the presence of unusual gas concentrations, shall require reparative or preventive maintenance. Installations which are intended as alternatives to maintenance shall be subject to approval.

Subsurface utility lines or pipes entering through openings in structure foundation walls or substructure foundation walls, on a Sanitary Landfill, which have been subjected to excessive loading as a result of differential settlement, shall be relocated, repaired, or replaced.

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